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An overview of energy balance compared to sustainable energy in United Arab Emirates

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ABSTRACT

This paper summarized an overview of energy balance and greenhouse gas emissions at UAE in order to prompt renewable and sustainable energy practices. Electricity demand has been increasing dramatically in the United Arab Emirates (UAE) in the last decade. Electricity production increased 5.39 TWh each year from 2000 (39.9 TWh) to 2013 (110 TWh), which means an annual increase of more than 13.5%. The electric power consumption has increased 5.14 TWh each year in the same period; which is 13.3% each year. The electricity consumption per capita is an indicator that places UAE in the group of highest consumption countries worldwide; namely, UAE ranks 10th in 2012 with 10.13 MWh per capita. UAE's population and economic growth are the main causes of a sharp increase in energy demand. On the other hand, UAE ranked 25th worldwide for CO_2 emissions. However, UAE is not in the top pollutant countries in the world with respect to CO_2 emissions per capita. More specifically, UAE has dropped from the 2nd position in the period 2000–2004 to 8th in 2010 and in year 2013 occupied again 2nd position among the global most pollutant countries. On the other hand, UAE has huge amount of available solar resources; the active and passive use of solar energy could be an approach to reduce even more the fossil energy consumption and the greenhouse gas emissions. It is essential to define the future role of the different sources of energy and to outline the required steps to move into a sustainable future energy system. These may achieve environmentally sustainable power development.

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1. Introduction

Energy is a continuous driving force for economic development, social advancement, and improved quality of life [1]. The growing world population combined with the fast depleting reserves of fossil fuels has encouraged researchers in the field of engineering to pursue development [2,3] and use of (RE) resources [4]. Climate change and fossil fuel depletion are the main drivers for the recent focus on finding alternative energy resources. RE is an obvious choice to reduce carbon dioxide and other pollutants contributing to global warming. However, since high cost of RE technologies is the main obstacle facing the diffusion of RE power generation, economical and political interventions are inevitable. These interventions include legislation, incentives to investment, energy generation targets, guidelines for energy conservation, strategies to stimulate the energy industry, and taxation [5]. Economic support policies that encourage investments in new technologies promoting adoption of RE have been implemented in many countries. In particular, a variety of economic support policies for RE has been developed and implemented mainly in Europe and the USA [6]. The development of RE has been supported by the developed countries for many reasons including ensuring security of supply, minimizing the usage of fossil fuels, reducing GHG emissions, improving industrial capabilities and increasing local benefits through creating new jobs and economic development [7,8].

The power industry is one of the few industrial sectors, which affect prosperity of every sphere of economic and social life and exert a direct influence on general technological progress [9]. Due to rapid economic growth, the rising power demand requires many countries to make significant investments in power generation [10], transmission and distribution systems as well as in the development of demand side management strategies [11]. Aging electricity assets, economy growth, changing population distribution, changing consumption patterns and environmental constraints, such as the climate change effect, are all driving the need for upgraded electricity infrastructure and for the use of sustainable power generation technologies [12]. The investment and operating choices made will have significant implications for the consumers, investors, environment and the economy [13]. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology was to remain constant and if overall quantities were to increase substantially. In order to control greenhouse gas emissions and other primary emissions, such as sulphur dioxide and nitrogen oxide emissions, further developments on efficiency and RE production are required [14]. A sound United Arab Emirates (UAE) energy policy should encourage a clean and diverse portfolio of domestic energy supplies. Such diversity helps to ensure that future generations will have access to the energy they need. Renewable Energy Sources for Power Generation (RES-E) can help providing UAE future needs by harnessing abundant, naturally occurring sources of energy, such as the sun, the wind and biomass. Effectively harnessing these renewable resources requires careful planning and advanced technology. Through improved technology, UAE can ensure that those power systems will make use of clean, natural, renewable sources. RES-E technologies will not only help diversify UAE energy portfolio but they will do so with few adverse environmental impacts [15]. RES-E technologies tap naturally occurring flows of energy to produce electricity. UAE have significant potential for renewable resource development especially from the sun [16,17]. This non-depletable source of energy is domestically abundant and has less impact on the environment than conventional sources.

A known region for the huge resources of hydrocarbons constitutes the six Arab States of the Gulf, including Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and UAE. In these states, a large number of oil resources have been found, including some of the largest and even giant fields in the world. This area is one of the highest densities of hydrocarbon discoveries in the world. Looking at the undiscovered petroleum resources in the region, the US Geological Survey (USGS) argued in 2000 [18] that the region has an undiscovered crude potential of some 162 billion barrels (mean, around 17% of the world's total). In addition, Oman and Qatar are nowadays seeking to develop their capacity to export natural gas. In the same hand, the undiscovered resources of natural gas in the region were estimated to be at around 23.3 trillion m^3, or about 16% of the world's total [19]. According to the latest issue of British Petroleum (BP) Statistical Review of World Energy (2014), the region was the largest exporter of oil (crude and products), contributing 35% of total exports, being the oil production in the United Arab Emirates rose 250 kb/d to reach a record high (3.6 Mb/d) the highest since 1979.

Noteworthily, the energy sector in the GCC is the main source of CO_2 emission due to fossil fuel great usage [20]. The fact above is that the major and logical reason behind the development of RE has been relatively low in spite of the large geographical potential for the use of these solutions. Indeed, the impression of the RE community over several years has been that these countries are just not interested. Recently, something seems to have changed. These countries are starting a process of environmental awakening, since they have signed and ratified into the United Nations Framework Convention on Climate Change [17] and almost all of them (except Bahrain) have recently accessed the Kyoto Protocol [19]. However, the ratification of the Kyoto Protocol seems not to be sufficient enough and there is a lot to be done. A variety of constraints or conditions prevent RE investments from occurring. These constraints put renewable at an economic, regulatory or institutional disadvantage relative to other forms of energy supply in the region [19]. As example, Abu Dhabi, one of the world's largest producers of oil has actively attempted to diversify its energy economy in recent years through local and international RE investments as many other countries in the gulf region [21]. The aim is to use all available conventional and non-conventional energy resources for electricity generation for longer term period. The ultimate objective of UAE's policy is to maximize use of indigenous energy resources and minimize energy subsidies [22]. The goal of this paper is to provide an overview of energy balance compared to sustainable energy in UAE.

2. Geographical aspects of UAE

UAE is situated in Southwest Asia, bordering Oman and Saudi Arabia between the Gulf of Oman and the Arabian Gulf. UAE geographically lies between 22°50′26″ North latitude and between 51°56′25″ East longitude. It is in a strategic location along the southern approaches to the Strait of Hormuz, a vital transit point for world crude oil [4]. UAE consists of seven emirates, and each emirate is equivalent to a principality with its own government. The seven emirates are Abu Dhabi, Ajman, Dubai, Fujairah, Ras-Al-Khaimah, Sharjah and Umm Al-Quwain. The country shares borders with Oman and Saudi Arabia, it has a 650 km long coast and a surface area of 83,600 km^2 [23]. Abu Dhabi is the capital and second most populous city in UAE. Abu Dhabi lies on a T-shaped island jutting into the Arabian Gulf from the central western coast. The low latitude of the region along with a climate characterized by very small amount of rain or cloudy skies, permits high radiation levels to reach the ground surface in summer. The weather conditions are very hot and semi-arid during summer days becoming warm and humid at night. During winter, daytime conditions fall within the comfort zone, while the night times are cool and humid. Hence, UAE with its vast land, average sunshine of

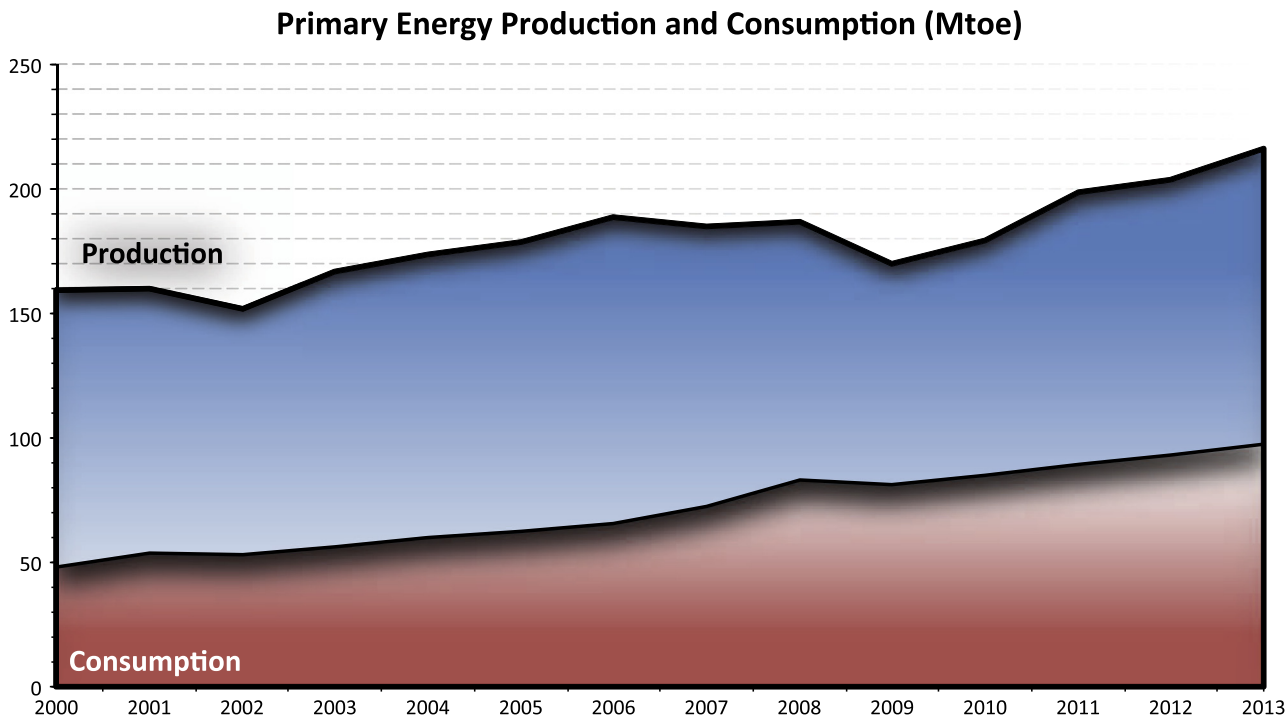

Fig. 1. Primary energy production and consumption in UAE.

ten hours and high global solar radiation on horizontal surfaces seems to be a positive candidate of solar energy [4]. UAE environment is characterized by high concentrations of airborne dust particles and high humidity, which tend to diffuse and attenuate the intensity of solar irradiance [23,24].

3. An overview of energy production and consumption

3.1. Primary energy production and consumption

UAE has two main sources of energy: oil and natural gas. Other sources such as coal and solar energy contribute marginally (less than 0.1%) towards meeting the ever increasing demand [25–27].

UAE currently has the world's 7th largest reserve of oil, which represents 5.8% of the world's reserve. And, UAE has the world's 4th largest production of oil, with 3.65 million barrels per day which represents 4% of the world's production. This is expected to be totally consumed in the next 80.7 years if production remains at these levels [23]. Although the population of UAE is around 0.1% of the world's population, they consume the 0.8% of oil produced worldwide. The energy consumed was 35% from burning oil and the remaining 65% from natural gas. Fig. 1 shows the evolution of energy production and consumption at UAE from 2000 to 2013 (last year with available data). For year 2013 the primary energy production (216.1 Mtoe) has increased by 6.1% compared to previous year, 16.9% compared to 2007, and 42.5% compared to 2002, where there was the lowest energy production (151.6 Mtoe). This means a growth of energy production of 3.9% per year from 2002. About the primary energy consumption, from 2013 (97.1 Mtoe) has increased by 4.1% compared to previous year (93.3 Mtoe), or increased by 33.9% compared to 2007 (72.5 Mtoe), and 84% (52.8 Mtoe) from 2002. This means a growth of energy consumption of 7.6% per year from 2002. Then in UEA, energy consumption growths almost two times than energy production in last 11 years.

Although some authors [23] think that the share of gas and oil in the energy mix for local production has not changed significantly in the period of 2001–2011, whereas the total energy consumption multiplied by 1.66 (5.2% increase per year), the data shows some differences.

UAE has also the world's 7th largest reserve of natural gas, which represents 2.9% of the world's proven reserve. However, because of high energy consumption, and a gradual shift towards gas-based power generation capacity, UAE has become a net importer of this substance since 2007. To meet local demand, 62% of the gas produced locally is used in addition to the imports [28]. It is worth noticing that 45% of gas consumed locally is used for electricity and water production, while 55% is consumed in the industrial sector.

Regarding to Gas Demand Projection, Business Monitor International produced a forecast in April 2009, summarized in Fig. 2. Gas demand is forecasted to grow from 37.9 BCM in 2003 to 68.3 BCM in 2013. Beyond 2013 it has been projected based on BMI's forecast trend rates between 2008 and 2013 of 14.8% per annum, also between 2013 and 2020 of 56.5% per annum. The energy demand prospects, coupled with current and future shortages of natural gas, motivated UAE leadership to promote a diversified energy mix that allows electricity generation from all conventional resources including renewable energy sources, coal and nuclear energy [22].

3.2. An overview of electricity production and consumption

Electricity generation has been increasing dramatically in UAE in the last decade, as is shown in Fig. 3. Electricity production increased 5.4 TWh each year from 2000 (39.9 TWh) to 2013 (110 TWh), this means more than 13.5% each year. Regarding electric power consumption this increased, accordingly, 5.1 TWh each year in the same periods; this is 13.3% each year. In 2013, the total consumed electricity was 105.4 TWh. So, regarding the net difference, it is shown that it is 3.8 TWh in average for this period. In addition, the lowest net difference was in year 2009 with 1.3 TWh, and the highest was in year 2007 being 8.8 TWh. Last year with data available (2013) was 4.6 TWh.

The electricity demand projection until year 2023 is shown in Fig. 4. It can be seen that the total of peak demand in 2014 was

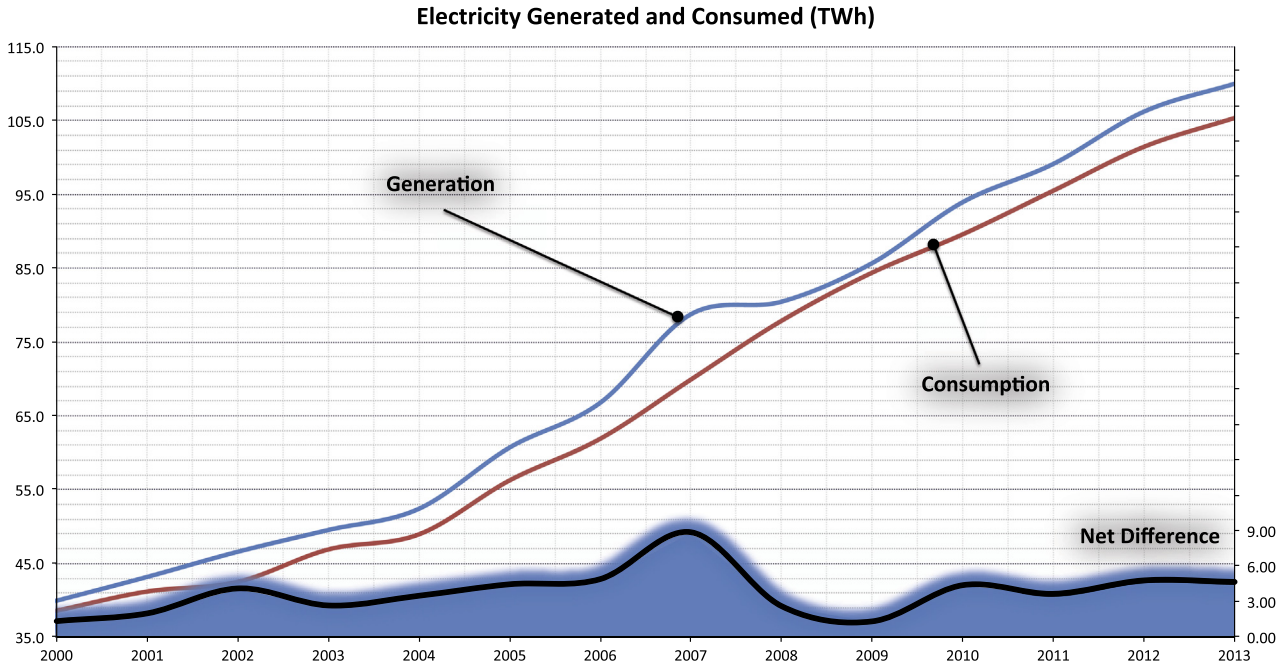

Fig. 2. Gas consumption forecast (BCM) – UAE.

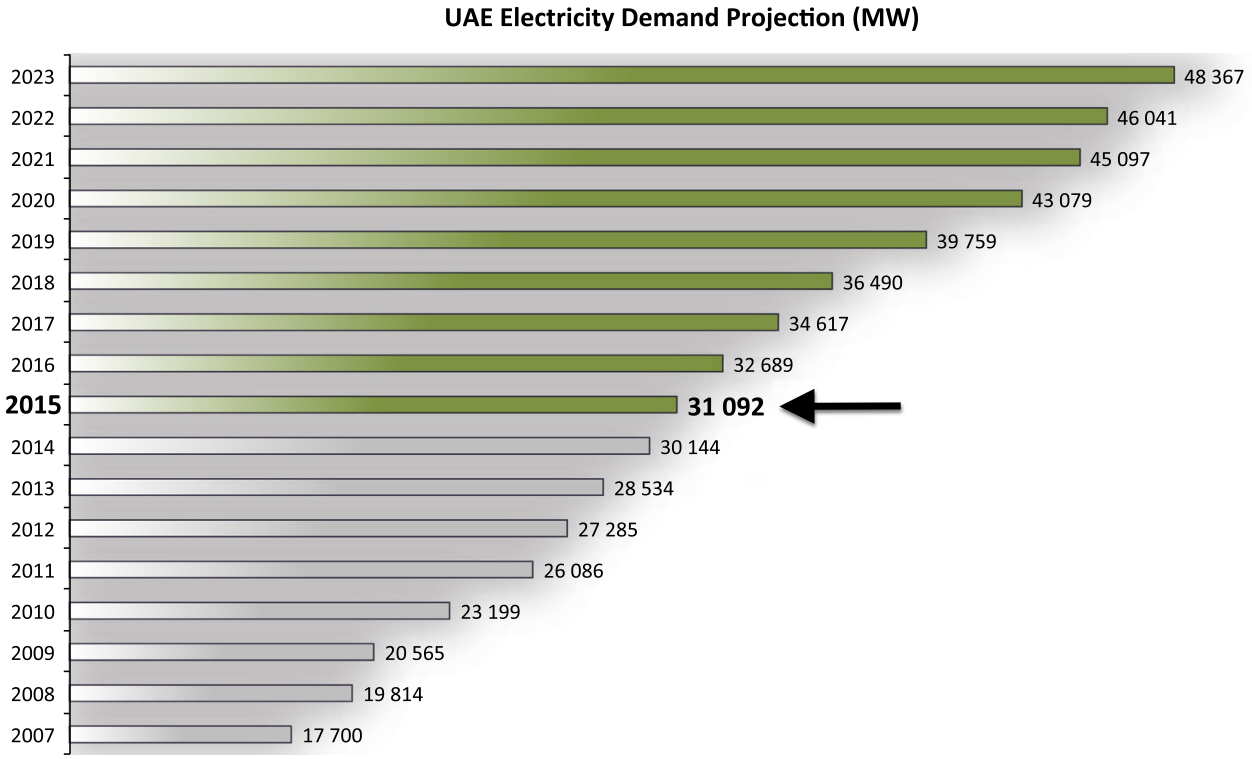

Fig. 3. UAE electricity generation and consumption (TWh).

30,144 MW. This last demand has increased by 70.3% compared to 2007. The forecast of total peak demand in 2023 will be 48,367 MW, which compared to 2014 means other 60.5% of increasing.

Power generation in UAE is entirely dependent on conventional fossil fuels. About 98% of electricity was generated from natural gas based on power plants in UAE [16]. In 2013, the Gross generation Capacity was 27,374 MW. There are four utility companies in UAE [29]: Abu Dhabi Water and Electricity Authority (ADWEA), Sharjah Electricity and Water Authority (SEWA), Dubai Water and Electricity Authority (DEWA), and the Federal Electricity and Water Authority (FEWA). Fig. 5 shows the generation of these companies from 2003 for UAE. The total Gross generation Capacity share for these companies was 12,217 MW in year 2003, with the following distribution: ADWEA (45.26%), DEWA (31.37%), SEWA (13.93%) and FEWA (9.43%). This distribution has changed along the time, e.g. in year 2007 was ADWEA (49.14%), DEWA (30.78%), SEWA (13.01%) and FEWA (7.07%). As we can see FEWA lose some percentage in these years. This situation has the same trend in the following years, reaching the actual situation in 2013: ADWEA

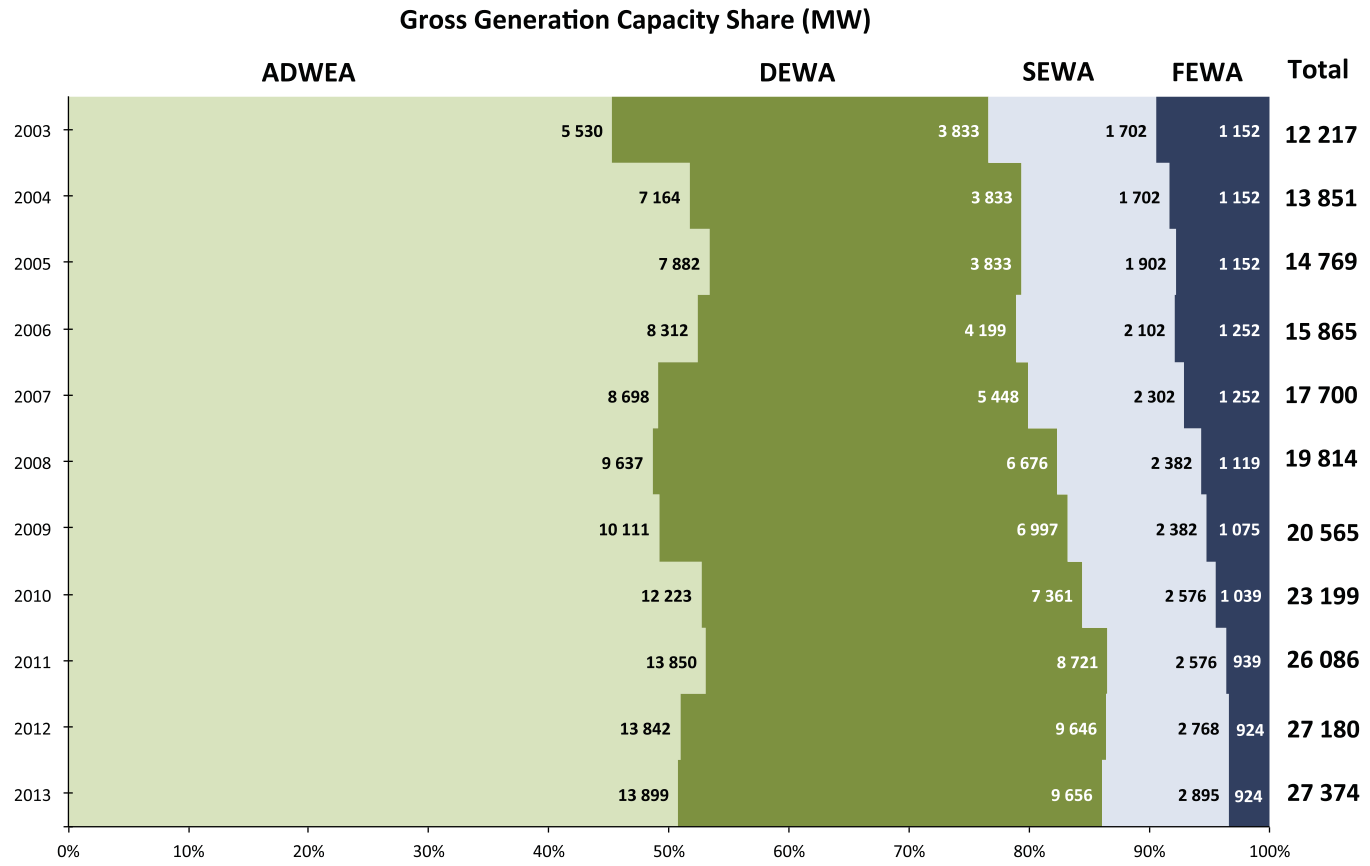

Fig. 4. UAE electricity demand projection (MW).

(50.78%), DEWA (35.27%), SEWA (10.57%) and FEWA (3.38%). It can be seen that two companies have increased their gross generation capacity in order to adapt the demand and other two remain in lowest percentage (SEWA and FEWA combined contribute only around 14%). For example, the Gross generation capacity for FEWA has decreased by 26.2% compared to 2007, and without increasing compared to 2012. According to National Bureau of Statistics in UAE (http://www.uaestatistics.gov.ae), in 2013 the number of power generation stations reached 40 stations, being 28 stations for both electricity generation and water desalination, and only 12 for electricity generation. The Electricity consumption 105,363 (GWh) in 2013 was increased by about 4% from year 2012 (101,454 GWh). Noteworthily, the electricity consumption at Federal Electricity and Water Authority (FEWA) and Sharjah Electricity and Water Authority (SEWA) was higher than the production of the stations of the two since 2008, so electricity was provided from Abu Dhabi Water ξ Electricity Authority (ADWEA), this covered about 57% in (SEWA) and 91% in (FEWA) of the electricity consumption.

This can be explained by the relatively high population, and high commercial and industrial activity in the emirates of Abu Dhabi and Dubai. Also, ADWEA exports electricity to other emirates to meet demand [18]. These four companies operate to meet a demand that is growing at the same rate as population growth: while population growth recorded between 6 and 11% per annum [30], electricity demand was growing by 13.3% per annum until 2013 [30]. UAE Government estimates that the annual peak demand for electricity is likely to rise to more than 45,000 MW by 2023 (see Fig. 6), reflecting a cumulative annual growth rate of 1919 MW approximately each year from 2015 to 2023. Fig. 6 suggests that a capacity over 21 GW will be required between now till 2023 [31]. However, within this forecast, in the immediate future, are some developments of major energy intensive industries (aluminium) that account for a substantial share of the incremental demand. This includes the development made by the Abu Dhabi National Oil Company (ADNOC) which requires 1000 MW of generating capacity and the Emirates Aluminium smelter which was stated in 2010 and was supplied by its own 2000 MW power plant. Towards the end of the forecast period shown in Fig. 6 the growth rate flattens out to below 4.65% per annum [32]. The supply-demand balance for electricity is shown in Fig. 6. The 7.0% required reserve margin is based on the value assumed in the GCC interconnection study (after completion of the GCC interconnection) but this appears very low.

Although some authors [33] think that electricity consumption in UAE has increased exponentially in the last three decades, the real growth is linear from 2003 to 2013 as it is shown in Fig. 3, where the relationship can be explained as $EC[\text{TWh}] = 5.61x[\text{year}] - 11,207$ with $R^2 = 0.98$.

3.3. Electricity generation per capita

It has been suggested in several studies that there is a strong correlation between the GDP per capita and energy consumption per capita and electricity consumption per capita [34–36]. Therefore, in order to assess electricity consumption per capita in UAE, a comparison between countries with similar GDP per capita for year 2014 as UAE (49,883 USD) is made Hong Kong (55,383 USD), United States (54,609 USD), Switzerland (47,603 USD), Canada (44,377 USD) and Australia (44,406 USD) [23]. In order to compare the electricity generation per capita worldwide, Fig. 7 is presented. We can see that the highest generation is widely spread across the world, mainly industrialized and rich countries and also others with extreme climate

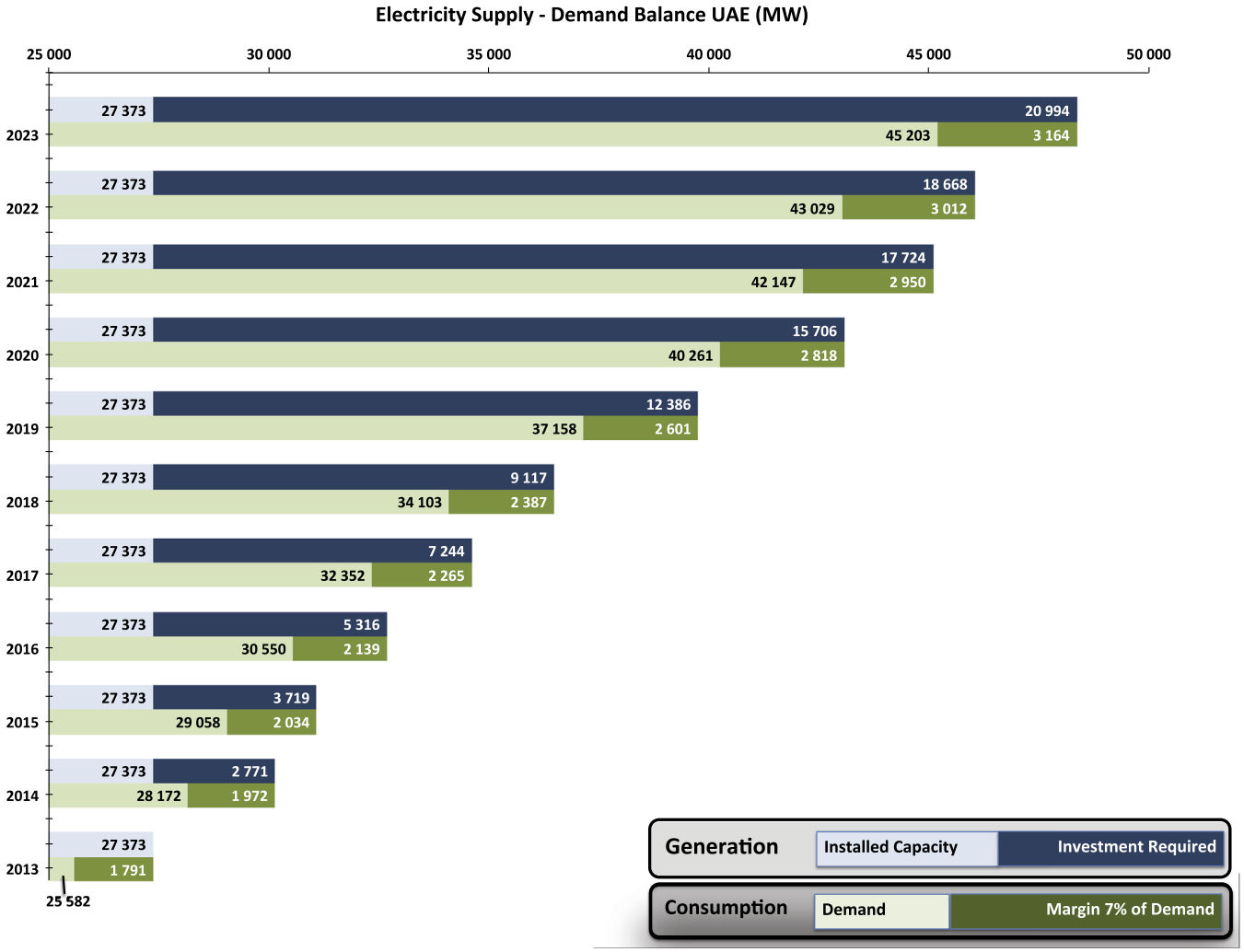

Fig. 5. Gross generation capacity (MW) for UAE.

conditions (very cold winters or very hot summer). As an example of cold winter countries is Norway, Canada, Sweden, Finland and US; and as an example of very hot summer countries is Gulf countries: Kuwait, Qatar and UEA. UAE is the 10th world largest consumer of electricity per capita [30], see Fig. 8. To put this in perspective, the world electricity consumption was increasing by 3.7% per year during the same period of time, and the world's population was also growing at a similar rate [30]. With regard to electricity consumption, 34–37% has been consumed in the residential sector, 30–37% by the commercial sector, 7–12% by the industrial sector, and the rest 19–27% has been used in other applications [23]. If the attention is paid to electric power consumption countries per capita, we find similar results as generation per capita. Fig. 8 shows the top 21 electric power consumption countries (kWh per Capita). UAE ranks 10th among the 21 countries with higher consumption per capita in the world. These values reflect very high energy consumption per capita in UAE (10,133 MWh per capita in 2012). Among the 21 countries with higher consumption per capita, Iceland ranks the 1st with 52,819 kWh and 2nd Norway with 23,016 kWh. Fig. 8 highlights some Gulf Countries as UAE, Kuwait, Qatar, Bahrain, or Saudi Arabia.

We can see that the highest consumption is widely spread across the world. If we make a deeper analysis, see Fig. 8, there are basically three kind of countries: very cold countries as Iceland or Norway, industrialized countries or with highest concentration of population as USA or Korea, and others that are energy producer as Gulf Countries (UAE, Kuwait, Qatar, Bahrain, or Saudi Arabia). Among the 21 countries with higher consumption per capita in the world; UAE ranks 14th in 2011. These values reflect very high energy consumption per capita in UAE (9.389 MWh per capita).

Electricity tariffs in UAE have some special regulation. For the cases of the Emirate of Abu Dhabi and the Emirate of Dubai are tabulated in Table 1 [37]. Electricity customers with consumption in excess of 1MW may in certain circumstances is entitled to cost reflective large user tariffs (See Table 2) [31]. UAE companies introduced a new tariff structure known as slab system (See Table 3) (http://www.moenr.gov.ae). Average individual electricity usage at the time was said by DEWA to be 20,000 kWh per annum, placing Dubai among cities with the highest consumption per capita in the world, as an example in Spain the average is 5600 kWh per annum per capita [11]. However, consumers, whether commercial, educational or residential who did not introduce measures to reduce consumption after the introduction of the slab tariff will have seen that electricity bills in some cases soar by over a million dirham [31]. The six Gulf Countries should be fully aware that they cannot depend on oil for their income forever, especially in the prevailing situation of price fluctuations, the rapid population growth and consequent increase in demand for electricity. The governments, the private sector and the general public should realize the inevitability of putting climate change issues on the top of the list of priorities in the process of economic and social development [19]. In these cases the bioclimatic architecture would help to improve this situation [38].

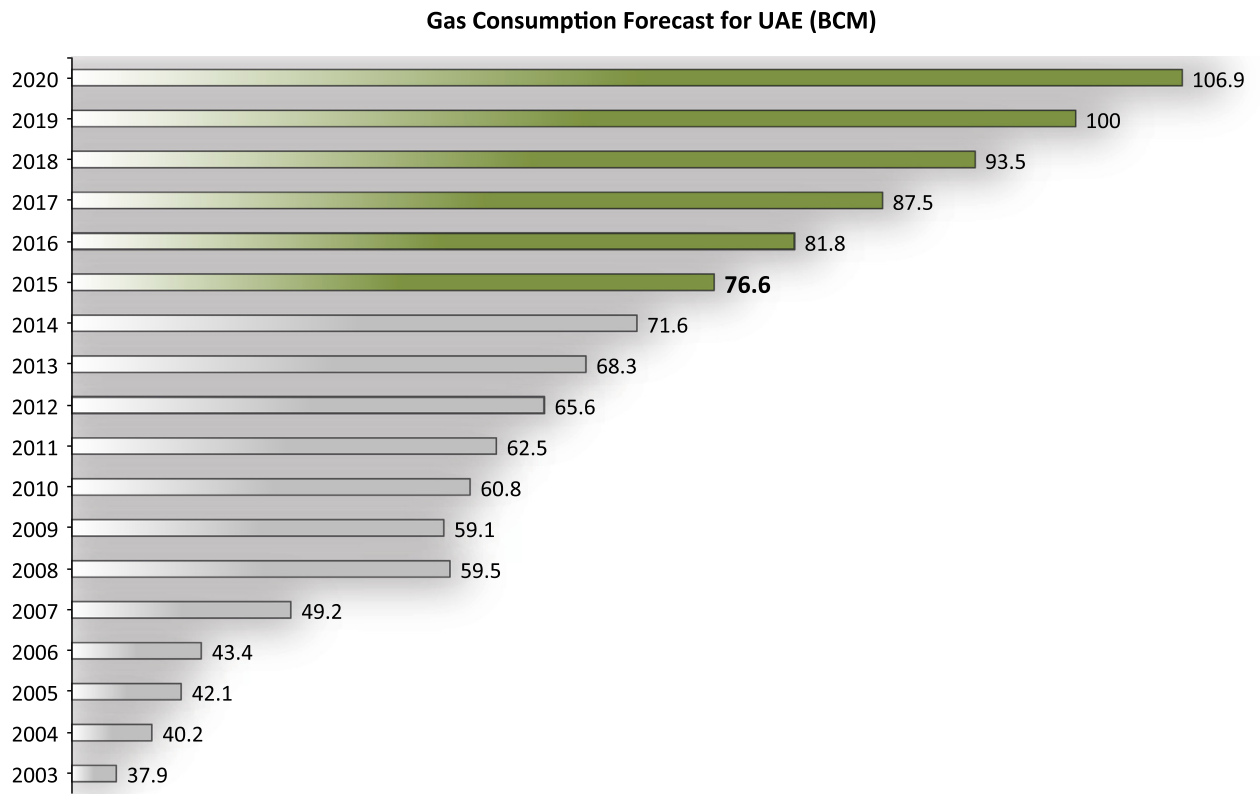

Fig. 6. Electricity supply–demand balance, UAE.

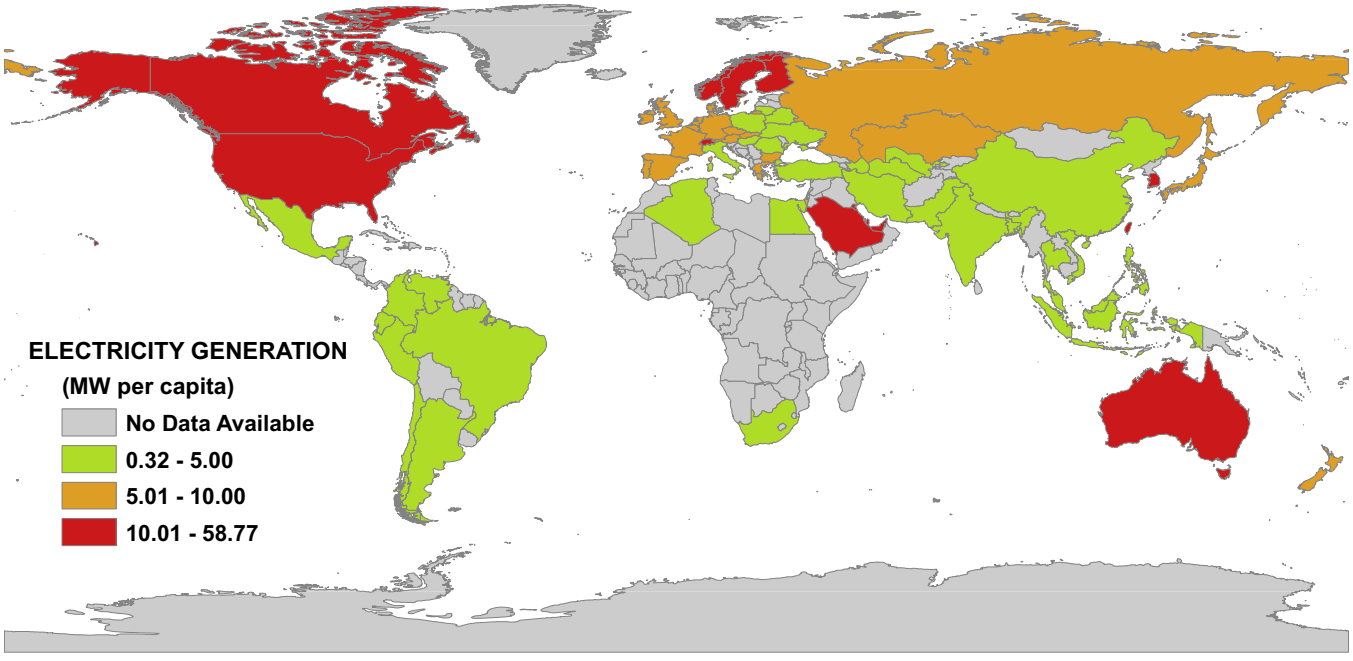

Fig. 7. Electricity generation per capita worldwide.

4. An overview of CO_2 emissions

Carbon dioxide (CO_2) is a foremost GHG (GreenHouse Gas) contributor to threatening global warming and climate change. Fig. 9 shows a worldwide distribution of CO_2 emissions, where it can be seen the correlation to electricity generation per capita worldwide, shown in Fig. 7.

Regarding the evolution of CO_2 emissions only in UAE, Fig. 10 shows UAE historical CO_2 total emissions (Mt) from and gaseous fuel CO_2 for UAE, so for the last year, the total CO_2 emissions were 253.7 Mt and gaseous fuel CO_2 was 131.2 Mt for the same year. If these data are analyzed for decades, first from 1990 to 1999 and then from 2000 to 2013, it shows that they follow a similar pattern for both CO_2 emissions and CO_2 emissions from gaseous fuel consumption. The

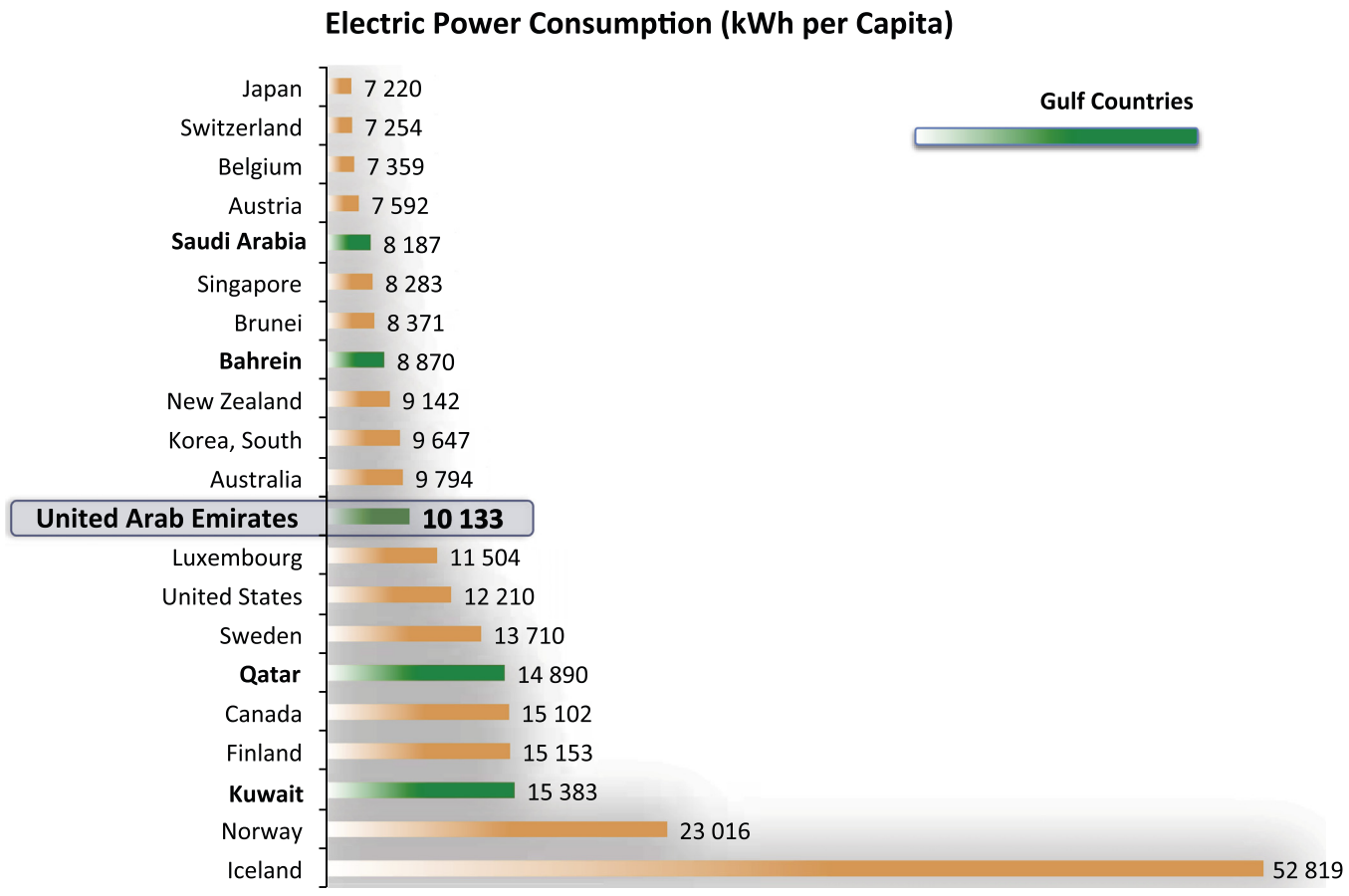

Fig. 8. Top 21 electric power consumption countries per capita (kWh per capita).

Table 1
Electricity tariffs in UAE.

Emirate	User type	Tariff (US$c/kWh)	Remarks
Abu Dhabi	National	1.36	Flat rate
	Non-national	4.08	Flat rate
	Industrial	4.08	Flat rate
	Commercial	4.08	Flat rate
Dubai	Residential	5.45	Below 2000 kWh/month
		12.12	Above 2001 kWh/month
	Industrial	5.45	Below 10,000 kWh/month
		12.12	Above 10,001 kWh/month
	Governmental	5.45	Below 10,000 kWh/month
		12.12	Above 10,001 kWh/month

Table 2
Large user tariffs for electricity (ADWEA, UAE).

	Peak: Midday–Midnight	Off-peak: Midnight–Midday
Large user tariff, US Cents per kWh		
Summer (June–September)	3.38	2.73
Winter (October–May)	2.73	2.73

Table 3
Electricity tariff, ADWEA, DEWA, FEWA and SEWA UAE. Source: Ministry of Energy - UAE (http://www.moenr.gov.ae/) – report issued in year 2014.

Customer category	Electricity tariff: Fils (US Cents)/kWh							
	ADWEA		DEWA		FEWA		SEWA	
	Fils	US Cents	Fils	US Cents	Fils	US Cents	Fils	US Cents
Residential (kWh)								
1–2000	15	4.08	23	6.26	23	6.26	30	8.17
2001–4000			28	7.62	28	7.62		
4001–6000			32	8.71	32	8.71		
6001 and above			38	10.34	38	10.34		
Commercial (kWh)								
1–2000	15	4.08	23	6.26	23	6.26	30	8.17
2001–4000			28	7.62	28	7.62		
4001–6000			32	8.71	32	8.71		
6001–10,000			38	10.34	38	10.34		
10,001 and above			38	10.34	38	10.34	35	9.53
Industrial (kWh)								
1–10,000	15	4.08	23	6.26	40	10.89	40	10.89
10,000 and above			38	10.34				
Governmental (kWh)								
1–10,000	15	4.08	23	6.26	23	6.26	40	10.89
10,000 and above			38	10.34	38	10.34		

first period (1990–1999) has an annual increase of 44.5 Mt and 26.3 Mt, respectively. However in percentages compared to 1990, this represents an increase of 53.6% for CO_2 emissions, and 85.7% for CO_2 emissions from gaseous fuel consumption in these 9 years. This indicates that emissions from gaseous fuel consumption have almost doubled in 1990s decade. For the next extended decade, a similar behaviour is observed; with an annual increase of 94.3 Mt and 55.4 Mt, respectively based on year 2000. Again in percentages, this

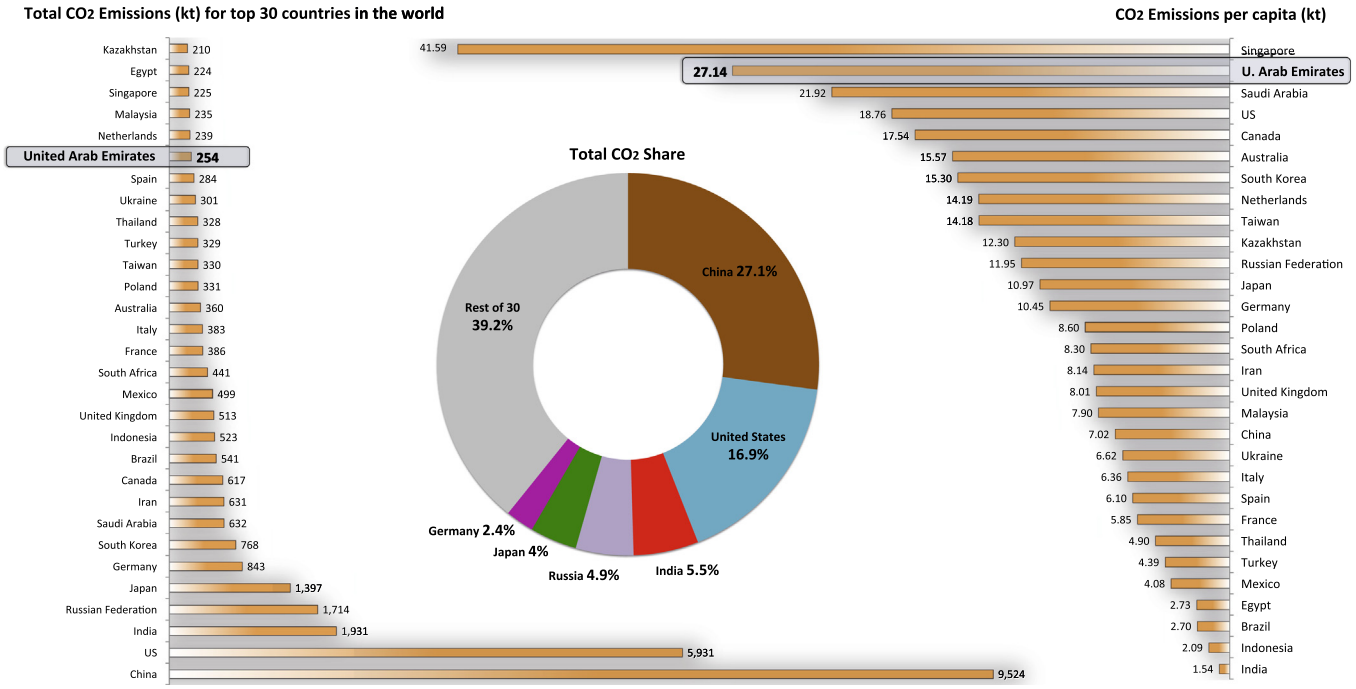

Fig. 9. CO_2 emissions per capita worldwide.

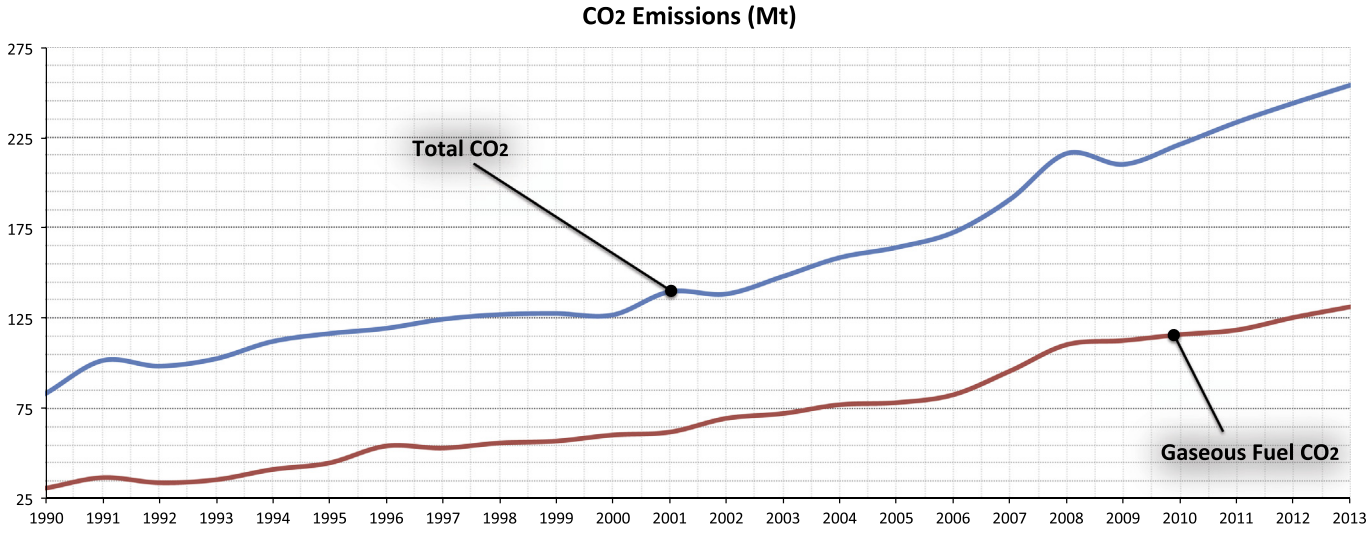

Fig. 10. CO_2 emissions in UAE for 1990–2013.

represents an increase of 74.4% for CO_2 emissions in these years, and 91.7% for CO_2 Emissions from gaseous fuel consumption. So emissions from gaseous fuel consumption also have almost doubled in the first decade of the century.

Vital contributor to eliminating the CO_2 emission is the renewable energy sources, although most of these sources are still immature and under development yet [10]. Electricity generated by fossil fuels is responsible for almost half of the country's emissions [39]. As a result of a fossil fuel based energy generation capacity, UAE has a high ecological footprint as a result of 254 kt CO_2 emissions. Fig. 11 shows CO_2 emissions (kt) for top 30 countries in the world. Then for year 2013 (last data available) UAE ranked 25th worldwide. Fig. 11 shows in a circle, the main polluting the countries, where China has the 27.1% of world CO_2 emissions and USA has 16.9%, others countries like India 5.5%, Russian Federation 4.9%, Japan 4% and Germany 2.4% complete this list. These mean that more than 60% of CO_2 emissions among these 30 countries are produced by 5 countries in the world, and 50% by three of these countries. For these top 30 countries, the CO_2 per capita is analyzed also in Fig. 11. It is shown that UAE ranks 2nd position with 27.14 CO_2 emissions per capita (kt), being Singapore the 1st (41.59 kt) and Saudi Arabia the 3rd (21.92 kt).

Fig. 12 shows the evolution of CO_2 emissions (kt) per capita for top 10 countries (ranking based on year 2013). So, UAE has 27.14 metric tons of CO_2 emissions per capita; this rank UAE the 2nd worldwide in last year, whereas in previous years ranks 8th (2010) or 5th (2008 and 2007). This rank is lead in 2013 by Singapore which has 41.59 metric tons per capita. Others Gulf Countries are also in this rank, e.g. Saudi Arabia (3rd) which has 21.92 metric tons of CO_2 emissions per capita. These emphasize the possibility to produce energy with alternative energy sources as solar systems in order to continue decreasing the CO_2 emissions and so continue lowering in positions of countries with more CO_2 emissions per capita. This will contribute to sustain economic development in

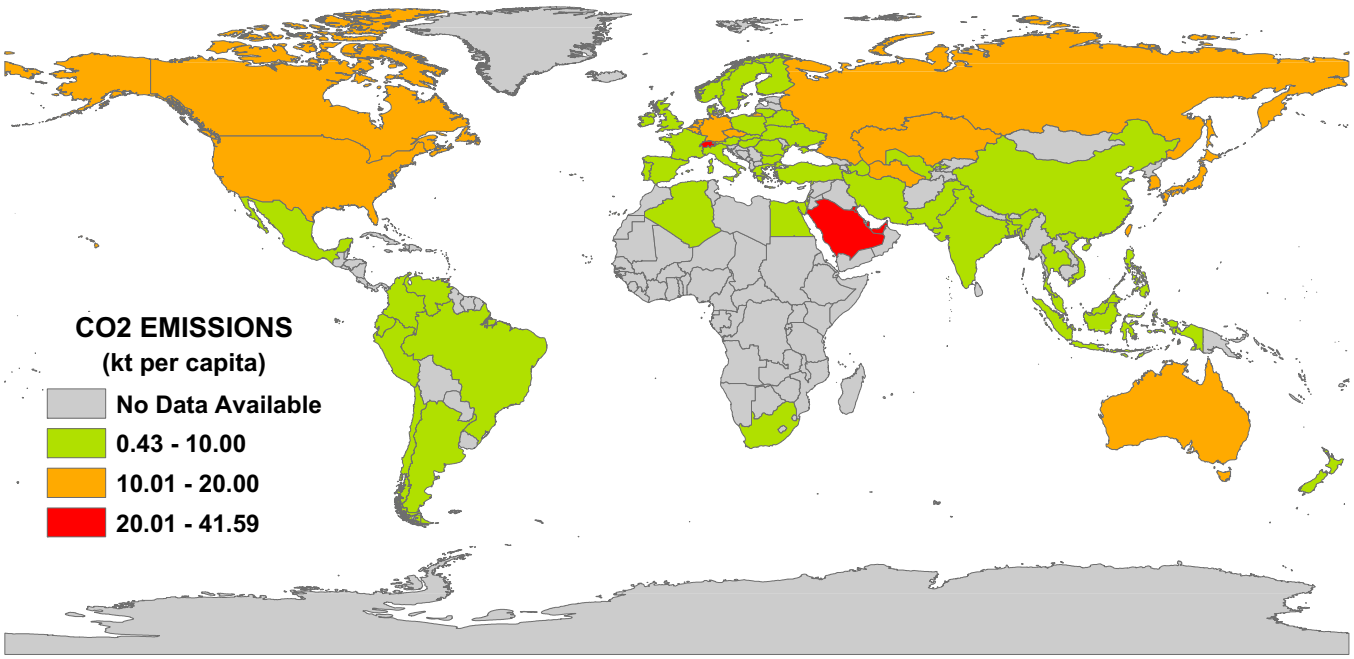

Fig. 11. CO_2 emissions (kt) and CO_2 emissions per Capita (kt) for top 30 countries in the world.

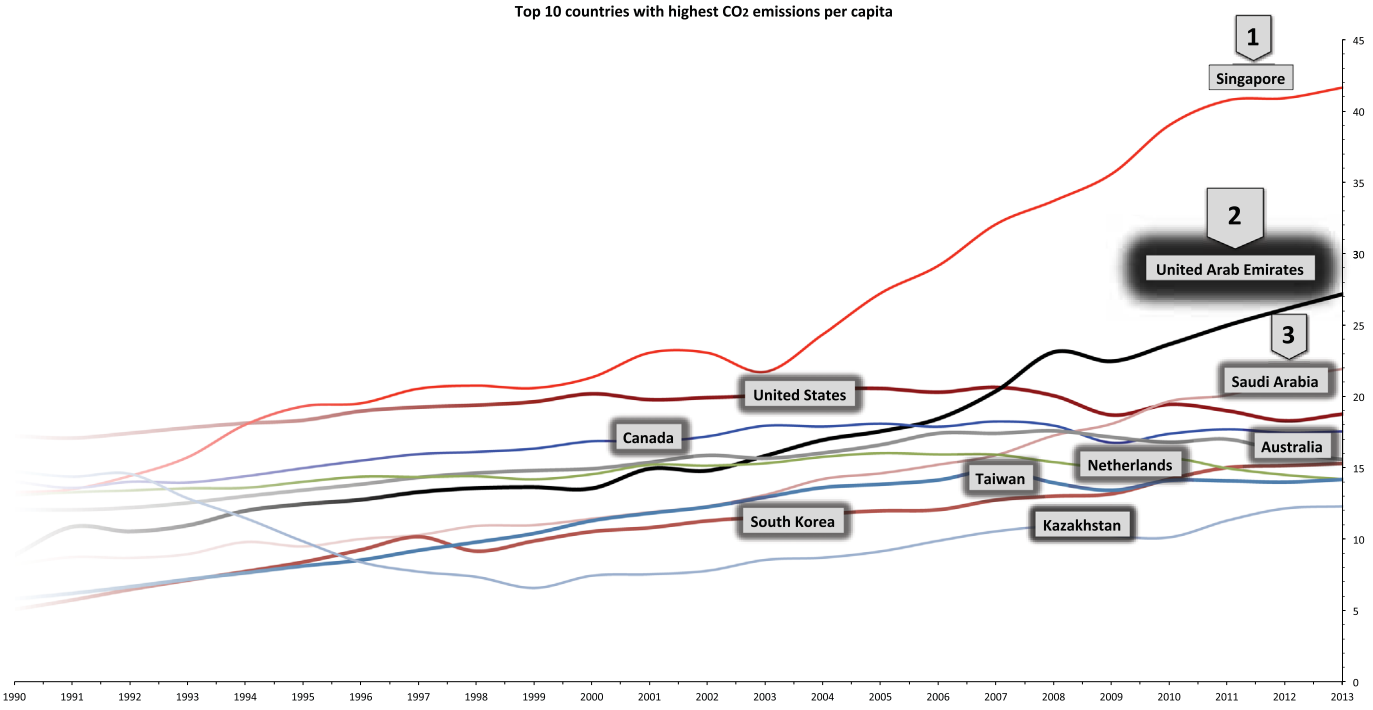

Fig. 12. Evolution of CO_2 emissions for top 10 countries.

the short, medium and long terms and the worldwide environmental protection [23].

5. Renewable energy resources

5.1. Previous efforts and integration of solar RES-E technologies at UAE

The cost of electricity production in UAE is lower than for non-oil-producing countries because of the fact that UAE is a main oil production country. In addition, the electricity bills are heavily subsidised [40,41]. Currently UAE has not officially adopted the use of renewable power, where priority has been focussed on traditional ways to generate electricity rather than on renewable directions [42].

Some of well known advantages of RE are the lack of environmental hazards such as acid rain and greenhouse warming, its safety and the lack of harm for the environment. On the contrary, the conventional energy pollutes air and water and its availability is limited. However, most of the RES are more expensive than conventional as fossil-fuel or nuclear sources. This makes the RE dependent on some form of financial subsidies for implementation. The subsidies are usually given to RE's as market launch

programs, e.g. in Germany for the area of renewable heating sources [43]. This makes the that RE map has been dominated by countries with a completely different energy portfolio to oil producing countries. The next RES impetus came as a result of increased recognition of the global warming phenomenon and the role of fossil fuels in it due to high emissions of Greenhouse Gases (GHGs) during the combustion of fossil fuels, mainly CO_2 [42]. Fossil fuel is considered as a primary source of the steady increase in CO_2 concentration since the pre-industrial era. The annual emission of CO_2 from fossil fuel has increased from almost 23.5 Gt in the 1990s to around 26.4 Gt in 2005 with an expected projection of 37.2–53.6 Gt CO_2 by 2030 [44,45].

UAE is known for its large oil and gas reserves, in addition, first UAE has one of the highest carbon footprints in the world [46] and second, the rate depletion of its main energy generation resource fossil fuel [47]. These factors highlight the need to establish an RE sector, so since 2006, it has been involved in various unprecedented activities in the RE sector. Even so the comprehensiveness of RE efforts in the region is still relatively low, because of both the large oil and gas resource base and the greater competitiveness of conventional energy supply technologies based on oil and gas. In particular, the efforts for RE development in the Arab States of the Gulf are formulated and presented in the three categories of the constraints (market technology, policy legislation and cost) [19]. In 2009 UAE government took a bold step by announcing its first RES-E policy, which set the goal that at least 7% of Abu Dhabi's power-generation capacity will come from RES-E technologies by 2020 [6,48]. An example of UAE strategy towards the use of RES-E technologies concerns the Masdar initiative [49], a multifaceted, multi-billion dollar investment in renewable and alternative energy and clean technology, aiming towards the world's first zero-carbon, zero-waste city. In UAE the need for effective RE policy making is becoming important due to political aspects that recommend using different resources to produce energy [14]. It is very important to set a clean development mechanism and to establish a RE industry. There is a need for consistent and stable policies and a true integration of RE resources and energy efficiency into energy system planning. In the meantime, UAE is taking giant steps forward to RE and energy efficiency programs [42].

Sustainability and the use of RE is prominent in the strategic plans of both Abu Dhabi and Dubai in terms of targets that need to be achieved in terms of RE contribution to the overall energy sector. Still there are many obstacles most important of which are the lack of policies and regulations that promote the use of RE in UAE. It is important to note here that although Abu Dhabi and Dubai are two of the seven emirates that makeup UAE, UAE is actually a federation of seven emirates as follows [42]: Abu Dhabi, Dubai, Sharjah, Ajman, Um-AlQuwain, Ras-AlKhaimah, and AlFujairah.

However, since the high cost of RES-E technologies is one of the main obstacles facing the large-scale integration of these technologies, economical and political interventions are inevitable. These interventions include the development of appropriate energy policies and strategies, such as, demand site management, legislation, incentives to investment, energy generation targets, guidelines for energy conservation, strategies to stimulate the energy industry and taxation [50]. Economic support policies that encourage investments in new technologies that promote the adoption of RES-E have been implemented in many countries [51]. In particular, a variety of economic support policies for RES-E have been developed and implemented mainly in the European Union and the USA. These policies comprise research and development incentive programmes, investment incentives, incentive taxes, incentive tariffs (mainly feed in tariffs (FiTs) and feed in premiums), voluntary programmes, compulsory renewable targets (production quotas) and tradable certificates [14].

An overall review of the existing constraints that can impede the development of RES-E technologies in the Gulf countries including UAE is provided in [19]. The main constraints that unfairly discriminate against RES-E development are mainly the result of a lack of commercial skills and information, the absence of relative legal and policy framework, the high initial capital costs coupled with lack of fuel price risk assessment as well as the exclusion of environmental externalities in the cost. Moreover, in the analysis provided in [33] three main components for large scale integration of PV power production were investigated (a) estimation of the energy production potential and financial feasibility of a hypothetical 10 MWp PV plant in Abu Dhabi, (b) assessment of the anticipated reductions in GHG emission and air pollutant emissions if the plant were constructed and (c) quantification of the social benefits of these reduced emissions. To estimate the energy production and financial feasibility of the hypothetical PV plant, the above analysis used RETScreen software (RetScreen International, http://www.retscreen.net). These findings confirmed the need of supportive measures in order for PV systems to be viable such as an appropriate FiT scheme. In particular for a positive net present value (NPV) the selling price of the electricity exported to the grid should be greater than 0.16 USD $/kWh.

In view of the above, it is crucial for UAE to integrate within its existing and future power system the necessary solar RES-E technologies in order to move towards sustainability [52]. For such an investigation, it is fundamental to perform an analysis of the new technical, economic and environmental status that the integration of such technologies will affect the current and long-term strategic planning of UAE generation system expansion. More importantly the economic aspects of solar RES technologies integration need to be taken into account [14].

5.2. Wind energy

Some authors [53] investigated that Saudi Arabia and UAE have limited potential for wind electricity generation with average wind speed about 2.5–4.5 m/s. But recent studies shows that the maximum wind speed is generated in the north eastern inner region in UAE, whereas the maximum wind speed potential is mainly derived from coastal areas with wind speed between 5 and 6 m/s (http://recrema.masdar.ac.ae/research-projects), this means a wind power density between 110 and 150 W/m^2 at 100 m above the ground, this data shows that this resource is as good as other countries like Mexico [12]. Several wind speed assessment studies were conducted in different regions in UAE to see the economic viability of deploying wind turbines. Efforts conducted jointly with DLR in Germany showed moderate values that do not exceed 5 m/s onshore and 7.5 m/s near the shoreline [54], making UAE wind energy potential the lowest among all Gulf countries [55], which can be harnessed at a height of 80 m, to achieve a full load hour of 1176 h per year (i.e. capacity factor of 13.4%). According to Alnaser et al. for wind energy to be economically viable, at least 1400 full load hours (i.e. capacity factor of 16%) are required [23]. However, a study conducted in Sharjah showed that wind speeds can reach values as high as 13 m/s in some seasons. Janajreh et al. [56] have measured wind speeds in Masdar City (Abu Dhabi) continuously for several months, at different heights between 0 and 50 m. Their conclusion is that the amount of wind in this part of Abu Dhabi is of class 1: poor to fair wind speed. Therefore, wind turbines with a low turning moment and characterized with a low cut-in wind speed can be implemented. In addition to this, it varies significantly during the year [56]. The investigators reveal that they could not go beyond 50 m in height because Masdar City is near the airport, where no structures should exceed 70 m. The authors suggested that wind speeds at higher altitudes should be

Table 4
RE projects summary.

Projectno.	Project name	Project description and project execution by	RE type used in the project and the importance	Project: capacity, budget and status
1	**Solar Power Facility called Shams 1, Masdar (Abu Dhabi's renewable energy company)**	1. Solar power facility that will be built near the capital of the UAE.	1. Using Concentrated Solar Power (CSP)	1. 100 MW
		2. This plant will offset 170 thousand tons of CO_2, annually.	2.–be the largest concentrated solar power plant in the world, extending over 2.5 km^2 and generating green power for 62,000 homes.	2. Shams 1 is the world's largest concentrated solar power plant in the Middle East.
		3. Masdar Company will work with Abengoa of Spain (a company that has 493 MW in operation and construction using trough, tower and photovoltaic technologies)	3. Shams 1 is registered as a project under the UN's Clean Development Mechanism (CDM), and is eligible for carbon credits. It is the first (CSP) plant registered under the CDM and the second project registered for Masdar.	3. (500–700) US$ million Construction began late 2010 and be completed within two years
2	**Hydrogen Power Plants (Commercial)**	1. One of the world's first Commercial hydrogen power plants.	Using Hydrogen power.	1.500 MW
		2. Masdar officials announced a deal with British Petroleum and Rio Tinto for the emirate.		2. At least $ 2 billion
3	**Masdar City**	1. Masdar City will be 6 km^2 walled community designed to be car-free and served by magnetic trains. In addition a desalinization plant for water will run on solar power.	Using Solar Power	1. If all goes according to the plan, 50,000 people will be living in the city by 2016, many of them working for the RE businesses.
		2. Masdar City		
4	**Masdar City (RE Project)**	1. Masdar City, mostly solar powered using traditional rooftop photovoltaic panels as well as from a 20 MW wind farm.	1. The city get its water from a solar powered desalination plant	1. Capacity is 20 MW
5	**Shams Tower project in Dubai**	1. Shams Tower project at Yas Marina F1 Circuit in Dubai was Completed.	1. It is a PV Solar Electricity	1. It is a 291 kWp PV (Shams Project).
		2. It is a VIP viewing tower for the 2009 Formula 1 Etihad Air ways Abu Dhabi Grand Prix.		2. Produces 450 MWh of electricity per year
6	**MW Solar Thermal Projects in (Ras Al Khaima – UAE)**	1. It is circular Solar Islands with a diameter of 5 km and height of 20 m consisting steam storage, carrying the termosolar concentrator solar power (CSP) panels placed on a membrane.	1. It is the first rotation test of the solar Islands prototype, constructed in the Emirate (Ras Al Khaimah) at UAE	1. Capacity: 1 MW rotating solar Island project
		2. In addition,The platform can be floated on high sea or land.		
		3. The concept was made by CSEM, Switzerland (http://www.csem.ch.)		
7	**Solar power for water heating at Burj Khalifa**	1. Using on the top roof of the offices at Burj Khalifa there are 378 collector panels, each 2.7 m^2 in area (total area of 1021 m^2), can heat the entire 140,000 L of water in approximately 7 h of day time solar radiation.	1. Solar Power was used in Burj Khalifa. Moreover the tower, which is the longest in the world (818 m), is using solar panels to heat 140,000 L of water every day, which will be distributed to homes and commercial entities within the tower.	1. The solar powered water brings energy savings equivalent to 3200 kW per day and 690 MWh of energy per annum.
		2. The solar heating system is installed and operated by SOLE UAE Solar Systems, the oldest solar thermal company in Europe.	2. This project is a perfect complement to the sustainable development initiatives spearheaded by the UAE.	
			3. The significant benefits include cost savings on energy uses, not only for the tower but the government utility provider too as well as reduction of pollution levels leading to a healthier environment.	

investigated to know the true potential of wind energy. In a separate study by Janajreh et al. where full year wind assessment was conducted in Masdar City at 50 m, it was reported that 3307 MWh of power can be generated annually, by using a 500 kW wind turbine to achieve a capacity factor of 7.5% and 657 full load hours [57]. The same study suggests that a 3.5 kW turbine would achieve 832.2 full load hours (i.e. Capacity factor of 9.5%) to generate around 29 MWh annually [57]. The potential of wind was also assessed in the emirate of Fujairah. Based on those analyses, it was announced that a wind generation capacity between 130 MW and 200 MW can be operated [54]. The potential of wind was also assessed in Sir Bani Yas Island (250 km southwest of Abu Dhabi). A wind turbine of 850 kW was deployed on the island for this purpose. Average wind speeds of 5.1 m/s were measured to achieve 1200–1300 full load hours (i.e. a capacity factor of 13.7–14.8%). The system in operation is grid connected, and it generates around 1 GWh of electricity per year, at a cost of 12.5 cents/kWh. Following this demonstration project, a wind generation capacity of 30 MW is envisaged in this location [54]. Shawon et al. have evaluated wind data measured at a height of 10 m in several regions in the (GCC) including three in UAE: Al Aradh, Sir Bani Yas and Al Mirfa [58]. The annual average wind speeds reported were 2.35 m/s, 3.86 m/s, and 4.27, respectively, and was classified of class 1: poor to fair wind speed (same conclusion as Janajreh and Taleb [56]). Shawon et al. suggested that these wind speeds would be suitable for water pumping [59].

5.3. Solar energy

Some efforts focussed on exploiting the solar energy potential have been made in UAE. In addition, some studies have been elaborated for using RE in bridging the gap between UAE supply of fossil fuels and the world energy demand. In particular, solar energy was studied to generate electricity through photovoltaic cells and hydrogen through electrolysis [60]. Solar energy is one of the most promising and important clean renewable energy sources for a sustainable future due to its lower environmental impacts compared to conventional sources, such as coal, oil or gas [61]. UAE lies between 22°30′0″ and 26°10′0″ North latitude and between 51° and 56°25′ East longitude which gives an indication of its good solar energy exposure what justifies why solar energy can dominate RE activities [62]. Historically, the amount of solar energy received in different regions in UAE has been evaluated in the past by using four approaches: (1) computation based on artificial intelligence techniques (artificial neural networks), (2) ground measurements, (3) processing of satellite imaging data, and (4) analytical or semi-analytical correlations [23].

Several studies report on ground measurement of weather parameters in different regions in UAE. In 1998, the Arab League Educational, Cultural and Scientific Organization (ALESCO) published the first solar radiation atlas for the Arab world [63,64], which was based on ground measurement of sunshine duration, global solar radiation and diffuse solar radiation in 207 cities. It was clarified that, based on the aforementioned solar radiation parameters recorded in Abu Dhabi City, Al-Ain and Sharjah, that UAE has among the highest yearly solar energy input in the Middle-East and North-Africa (MENA). However, Al Mahdi et al. have compared global solar radiation data recorded in several GCC regions: Abu Dhabi, Bahrain, Doha, Kuwait and Riyadh; and it was found that Abu Dhabi City has the least annual amount of global solar radiation, but also the lowest annual average clearness index, and the second highest annual duration of sunshine after Doha [65]. Since its establishment in 2012, the Research Center for Renewable Energy Mapping and Assessment at Masdar Institute in Abu Dhabi has conducted several research projects to use satellite imaging data to assess the solar energy resource in UAE [66]. Some of the efforts have focussed on studying the characteristics of the atmosphere such as humidity and airborne dust particles, and their effect on the incident solar radiation [23]. An average of the solar resource was evaluated for year 2012 (http://atlas.masdar.ac.ae) as: 900 kWh/m^2 for Diffuse Horizontal Irradiation, 1800 kWh/m^2 for the Direct Normal Irradiation, and 2200 kWh/m^2 for Global Horizontal Irradiation. Other authors show that this average daily energy input for the whole year (2009) was 18.48 MJ/m^2/day, this means 5.13 kWh/m^2/day [67], and further research shows that the solar radiation level was more than 400 W/m^2 throughout the year 2010, which suggests that concentrating solar collectors could be used here to great effect [68]. However, high concentrations of airborne dust particles and high humidity tend to diffuse and attenuate the intensity of solar irradiance. Satellite imaging data and ground measurement data have shown that the magnitude of these effects is seasonal and location dependent [69,70], which makes some solar technologies more suitable than others depending on the location [23]. For example, for the Emirate of Sharjah based on HelioClim database (http://www.helioclim.org), a yearly Direct Normal Radiation (DNI) is approximately 2106 kWh/m^2.During the months from March to October there is a considerable high sunlight radiation. This provides the fundamental grounds for the adoption of solar RES-E technologies for generating electricity. Furthermore, based on the available data in HelioClim, it is observed that all parts of UAE enjoy the same sunny climate and the same DNI. The area is exposed to sunlight radiation for a minimum of 8 h in December and a maximum of 14 h in June [14]. A recent study [61] on the assessment of solar energy potential over the United Arab Emirates using remote sensing and weather forecast data, confirm that PV power plants are more appropriate for UAE context than CSP power plants. Furthermore the most suitable areas for PV power plants are located in the eastern side of the country, instead for the CSP power plants, their most suitable areas are located on the coast nearby Abu-Dhabi and the extreme south of UAE.

5.4. Renewable energy projects in UAE

This section is an overview of RE projects in UAE, also the way of promoting RE in the oil rich UAE. Because of the potential of solar energy in UAE and its short history of performance, several companies and research institutions are working on pilot projects to develop an understanding of how different solar technologies perform under the real operating conditions. Some of these pilot installations are based on some exotic technologies that are not in the market yet such as a floating solar installation and a beam down concentrator, while others use mainstream technologies [23]. For instance, RE is new to UAE market, and that puts it in a competitiveness disadvantage [71]. Also, the workforce, institutions, and the infrastructure may not be ready to handle this change. Therefore, a RE strategy is needed. UAE has announced its vision 2030 to become an environmentally, socially and economically sustainable community [23].

Therefore, many projects in RE were made and planned (As shown in Table 4). Among them is the establishment of Masdar Company which is the pioneer and RE arm of UAE. The company has already invested USD $250 million in clean tech companies from around the world, and expects to launch a second and third fund in the near future. Masdar may have USD $15 billion to spend, although UAE earns USD $225 million in revenue from petroleum every day [55].

In addition, the name ‘Masdar’ has become synonymous with the push for RE technology in UAE [72]. Moreover the global media coverage on Masdar City also contributes to a rising public awareness regarding renewable energies in the whole world. Masdar City might start a process in the Gulf countries follow ing the successful Norwegian example by promoting renewable energies on a domestic level [40]. It is important to identify the limitations that stand in the way of promoting RE in UAE. Although UAE has sufficient solar resources for electricity exploitation, the RE resource area is considered as a limitation in itself. The main limitations are [42]

- The electricity industry is controlled individually by each of the 7 emirates. This leads to defragmentation and some discrepancies in the regulations between the different emirates.
- The low cost of electricity is mainly due to large government subsidies, e.g. the cost of electricity in the emirate of Abu Dhabi is approximately 4 US cents per kWh.
- There are no provisions for feed-back of excess power back into the electricity grid.
- There is no direct taxation system that can be used to give support for using RE.
- Transparency of regulations.
- Provisions are to allow and control private–public cooperation and independent power providers.
- There are no regulations or requirements for mandatory use of RE.

6. Conclusions

This paper summarized an overview of energy balance and greenhouse gas emissions at the United Arab Emirates (UAE) in order to prompt renewable and sustainable energy practices. Indeed, UAE should be fully aware that they cannot depend on

oil for their income forever as the growth of its population and the consequent increase in electricity demand. UAE supplies 4% of oil consumed worldwide and has 5.8% of the world's oil reserve, which is expected to be totally consumed within the next 81 years. It is also worth recalling that UAE has become a net importer of gas since 2007. It was also found that around 75% of electricity is consumed in buildings, among which 40% goes to cooling and air conditioning. These last needs make the electricity generation per capita at UAE is in the group of highest consumption worldwide; UAE ranks 9th with 11.9 MWh per capita. In regard to energy consumption, UAE ranked 25th worldwide for CO_2 emissions, but regarding CO_2 emissions per capita it was observed that UAE is one of the most pollutant countries in the world; UAE has dropped from the second position in the period 2000–2004 to eighth in 2010 but in year 2013 occupied the second position again. Accordingly, UAE has available good solar resources; the active and passive use of solar energy could be an approach to reduce the fossil energy consumption and the greenhouse gas emissions. It is essential to define the future role of the different sources of energy and to outline the required steps to move into a sustainable future energy system. It has been shown that UAE needs a policy to unlock the renewable energy market and to start to develop in the renewable energy sector. This will contribute to sustain economic development in the short-, medium- and long-term and the reductions of greenhouse gas emissions also will contribute to the worldwide environmental protection. These may achieve environmentally sustainable power development in UAE.

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