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Impact of Reforms on Efficiency, Fuel Savings and Emissions with Optimal Fuel Allocation to Power and Water in Abu Dhabi

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ABSTRACT

This paper analyses the impact of reforms on fuel efficiency, fuel savings and carbon emissions in Abu Dhabi power and water sectors. The actual operating results from year 2000 to 2010 have been analysed. The fuel consumptions in power and water desalination facility have been allocated to power and water outputs. The results exhibits significant efficiency gains and environmental benefits include: a 25% reduction in specific fuel consumption, a 13.55% fuel saving (811,200 TJ) and a 45 million ton reduction of emissions in the post-reform period. However, despite the efficiency gains, per capita emissions are increased by 17%.
KEYWORDS: Fuel Allocation, Heat Equivalent, Clean Development, Policy, Regulation.

1. INTRODUCTION

The Emirate of Abu Dhabi is one of the seven emirates of the United Arab Emirates (UAE).Abu Dhabi's economy is dominated by oil, and its power generation and industry are reliant on fossil fuels [1], resulting in high carbon emissions. A 2008 plan by the government of Abu Dhabi, The Abu Dhabi Economic Vision 2030[2],sets targets for sustainable development with diversification of the economy. Energy (oil and gas), petrochemicals, metals and other sectors are expected to grow, and the non-oil share of the economy is predicted to be 64% by 2030.The GDP is forecast to swell by five times by 2030,with average annual growth of 6%through 2015 and 7% thereafter. The growth required to meet these targets will be energy intensive and will require more than a three times increase in power use (to approx. 33,730 MW) and a two times increase in water consumption (to approx. 1,262 million imperial gallons per day (MIGD)) by 2030 [3]. These demands will require a marked increase in fossil fuel consumption and carbon emissions, thereby expanding Abu Dhabi's carbon footprint.

Abu Dhabi has also been a leader in pursuing clean environment policies. It has ratified the Kyoto Protocol, and is a member of and the host of the first headquarters of the International Renewable Energy Association. It is also committed to hosting future energy summits to promote clean technologies and to researching and developing clean technologies through, for example, the Masdar initiative [4].The establishment of a sustainable economy is a policy priority of the Abu Dhabi government [2].This requires clean, reliable and viable energy generation, which can only be achieved through efficient power and water sectors.

As part of reforms implemented in 1998to improve efficiency, Abu Dhabi unbundled its vertically integrated Water and Electricity Department (WED) into production, transmission and distribution businesses; in addition, the private sector was invited to participate in the development and operation of production facilities [5]. Their forms introduced incentive-based regulation of the network businesses, which led to reduced transmission costs [6], competition between producers and increased efficiency [7].Fuel savings and emission reductions followed.

This paper analyses Abu Dhabi's existing power generation and water production, and its fuel consumption over the post-reform period 1999–2010 [1].Water and electricity production heat equivalents are checked against the pre-reform base year 1999,and the changes in thermal efficiency, specific fuel consumption and emissions are assessed. Significant reductions in specific fuel consumption and emissions are identified for both power and water.

2. POWER AND WATER IN ABU DHABI

Power and water needs of the Abu Dhabi consumers are met through combined facilities for power generation and seawater desalination. As per statistical leaflet of Abu Dhabi Water and Electricity Company for year 2012, nine facilities are operating with the total installed capacity for water and power of 916 million IG/Day and 13,842MW respectively. The feedstock used for the power and water production is fossil fuel mainly gas.

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2.1 Power and Water Structure

Abu Dhabi's Law No. 2 of 1998[5] transformed its vertically integrated power and water sector into corporatized generation, transmission and distribution businesses. The private sector became solely responsible for management and gained 60% ownership in production. The introduction of private involvement attracted new independent water and power producers (IWPPs) to initiate competitive green-field projects. The Abu Dhabi Water and Electricity Company (ADWEC) was created to act as sole procurer and seller of electricity and water in the emirate [8].The Regulation and Supervision Bureau (RSB), an independent regulator, was also created to regulate the water and electricity sectors [9].

The single-buyer commercial structure for Abu Dhabi's power and water sectors has ADWEC as the sole procurer[Figure-1].It buys from producers at prices competitively established through bidding, and it sells power and water to distribution companies at tariffs set by the RSB. The Abu Dhabi Transmission and Despatch Company is responsible for developing and maintaining the transmission system, dispatching generating and desalination units, and transmitting power and water to the distribution networks. There are two distribution companies: Abu Dhabi Distribution Company and Al Ain Distribution Company). They distribute power and water, and supply consumers at a regulated tariff in their respective territories. In 2006, the UAE connected all its constituent emirates through the Emirates National Grid for the exchange of water and power. Under special consent from the RSB, ADWEC exports its surplus power and water to the Federal Electricity and Water Authority, and also to corresponding authorities in other emirates, including those in Sharjah and Dubai[10]. In 2011, the Gulf Cooperation Council (GCC) Interconnection placed ADWEC in a wider network that enables it to exchange power both during emergencies and on scheduled terms with companies in nearby countries.

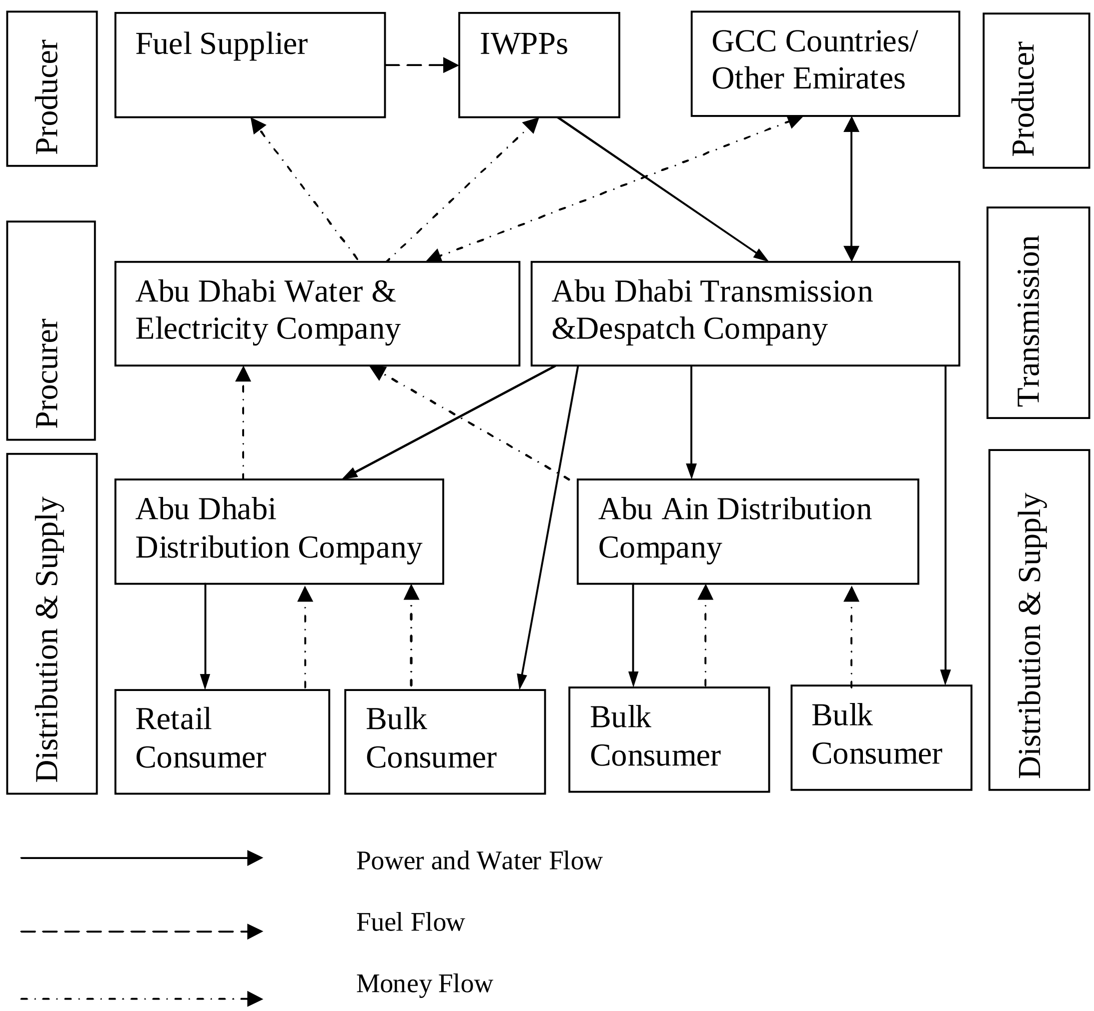

Figure1. Structure of Abu Dhabi Power and Water Sectors.

2.2 Fuel Structure

The restructured system has ADWEC responsible for fuel supply to power and water production companies. It procures the fuel from specific suppliers: Abu Dhabi National Oil Company is the sole supplier of liquid oil in Abu Dhabi; eastern gas plants are solely supplied by Abu Dhabi Gas Industries Ltd. And western gas plants are solely supplied by Dolphin Energy Limited, exported from Qatar. The average fuel mix over the period 1999–2010 was 97.29% from gas, 1.47% from crude oil (CO), 1.04% from gas oil (GO) and 0.2% from fuel oil (FO) [1].

3. METHODOLOGY & CALCULATIONS

The actual operating data from year 2000 to 2010 for gross power generation, gross water production, gross fuel consumption and the fuel mix have been taken from statistics of Abu Dhabi Water and Electricity Company [1].

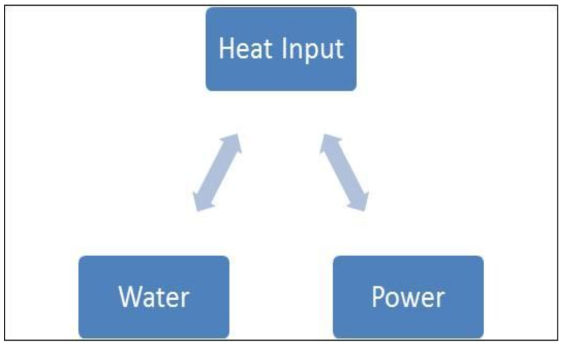

Figure-2 Heat Flow Logic in Power and Water Desalination Facility

In combined power and water facilities, the input heat is used in both power generation and water production [Figure-2]. This study uses an existing methodology for the allocation of gross fuel consumption to water and power production [11, 12]. First, the annual gross water production is converted to equivalent heat units by multiplying it by the heat value of 23,210 kJ/m^3 (100 Btu/IG) [11]. Similarly, the annual gross electricity generation is converted to equivalent heat units via its multiplication by a conversion factor of 3600 kJ/kWh.

The total thermal efficiency for power and water production (η_f) is the ratio of the equivalent heat of gross output for both power and water to the total annual gross fuel consumption. The calculation employs the thermal efficiency share for water (η_w), which is the ratio of equivalent heat of annual output water production to the total annual gross fuel consumption; it also uses the thermal efficiency share for power (η_e), which is the ratio of equivalent heat of annual gross electricity generation to the total annual gross fuel consumption. Using these water and power efficiency shares, gross fuel consumption allocation ratios for water and power production can be calculated. The gross fuel ratio for water production (F_w) is the ratio of thermal efficiency share for water production to the total thermal efficiency, and the gross fuel ratio (F_e) for power generation is the ratio of thermal efficiency share for power generation to the total thermal efficiency.

The specific fuel consumption for water production is the ratio of annual gross fuel allocated to water production(as allocated above) to the annual gross water production. The specific fuel consumption for power generation is the ratio of annual gross fuel consumption allocated to power (as allocated above) to the annual gross electricity generation.

Greenhouse gas emissions, predominately carbon dioxide (CO_2), are calculated by multiplying the Intergovernmental Panel on Climate Change (IPCC) tier 1 default emission factors for the combustion of gas, diesel, fuel oil and crude oil [13],the fuel ratio and the recorded gross fuel consumption.

4. RESULTS & DISCUSSIONS

4.1 Fuel Efficiency

Fuel efficiency increased in the period after the reforms (1999–2010), indicating better management and increased use of efficient technologies. The cumulative fuel efficiency gain was 34% over the whole period, equivalent to a compounded average annual gain of 2.69%. Gains of 185.25% in power generation and 220.87% in water production were achieved with an increase in fuel consumption of only 115.17% (Table1). These figures clearly demonstrate fuel and cost savings. The operating results also show a sustainable power and water ratio over the examined period. The recorded efficiency shares of power and water also suggest that the effective output heat is mainly attributed to power generation, with water production only accounting for a fraction of that.

Table1. Comparison of Fuel Efficiency Share between Water and Power.

	GROSS OUTPUTS & HEAT VALUE				ACTUAL FUEI	GROSS FUEL EFFICIENCY			
	Power generation		Water production		Total	Power	Water	Overall	
Year	Mkwh	TJ	km^3	TJ	TJ	η_e	η_w	η_f	
1999	17,508	63,028	311,065	7,220	288,325	0.2186	0.0250	0.2436	24.36%
2000	19,128	68,862	340,335	7,899	304,686	0.2260	0.0259	0.2519	25.19%
2001	20,495	73,782	389,825	9,048	328,468	0.2246	0.0275	0.2522	25.22%
2002	22,026	79,294	474,299	11,008	353,009	0.2246	0.0312	0.2558	25.58%
2003	23,112	83,202	541,638	12,571	368,265	0.2259	0.0341	0.2601	26.01%
2004	24,143	86,915	623,518	14,472	400,424	0.2171	0.0361	0.2532	25.32%
2005	25,424	91,525	736,438	17,093	434,688	0.2106	0.0393	0.2499	24.99%
2006	31,987	115,154	802,146	18,618	477,291	0.2413	0.0390	0.2803	28.03%
2007	38,592	138,933	861,822	20,003	511,628	0.2716	0.0391	0.3106	31.06%
2008	38,547	138,768	928,539	21,551	519,104	0.2673	0.0415	0.3088	30.88%
2009	42,645	153,521	990,151	22,981	566,808	0.2709	0.0405	0.3114	31.14%
2010	49,942	179,790	998,115	23,166	621,950	0.2891	0.0372	0.3263	32.63%

A graphic comparison highlights the annual fuel efficiency shares for electricity generation and water production (Figure-3). The maximum and minimum variations in efficiency components for power and water over the period 1999–2010 are also summarized in Table2.

Table2. Maximum and Minimum Variations in Efficiency Components**.**

Period	$\eta_{e\,\%}$	$\eta_{w\,\%}$	$\eta_{f\,\%}$
	Min–Max	Min–Max	Min–Max
1999–2010	21.1–28.9	2.5–4.2	24.4–32.6

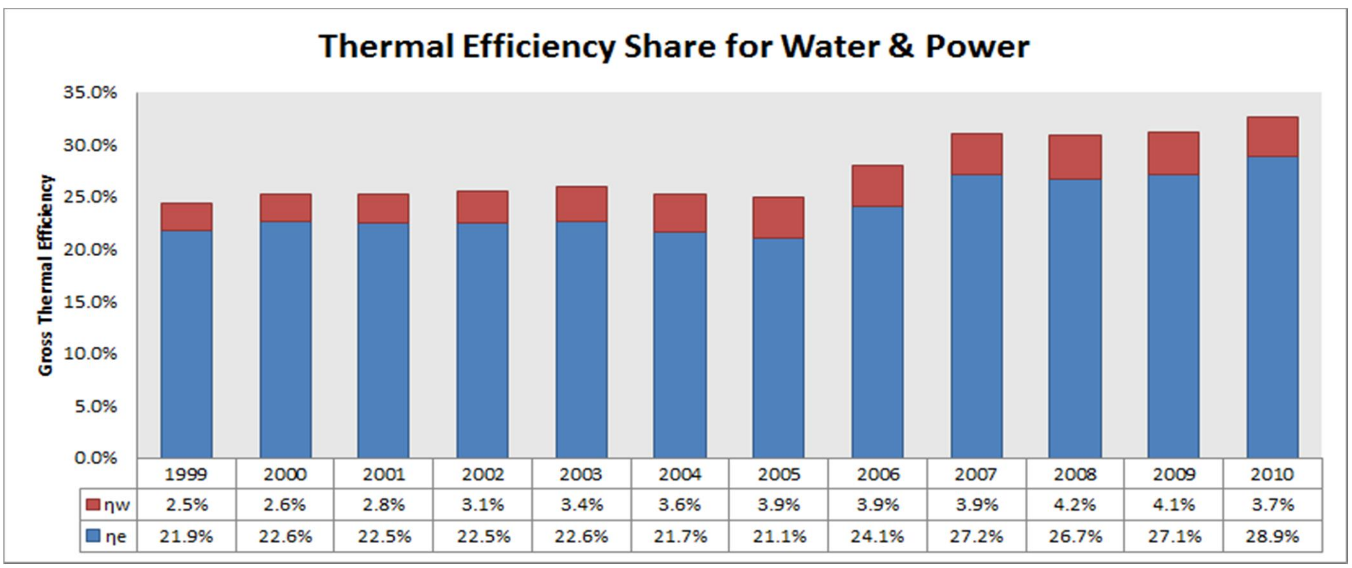

Figure 3. Comparison of Fuel Efficiency Shares for Water Production and Power Generation for 1999–2010.

4.2 Fuel Savings

The major part of the consumed fuel was used for power generation: it varied within the range 84.26%–89.72% (conversely, fuel for water production was within the range 10.28%–15.75%).Therefore, the onus for fuel efficiency and savings is on power generation. The specific heat rates for both power generation (in kJ/kWh) and water production (in kJ/m^3)decreased by 25.34% [Figure-4, Figure-5]. This resulted in a significant fuel saving of 811,200 TJ over the examined period, which in turn led to cost savings and emission reductions(Table3).

Table3. Comparisonof Annual Fuel Savings Due to Efficiency Gains.

	FUEL SHARE		SPECIFIC HEAT RATE		CALCULATED BASED ON 1999 DATA	ACTUAL 1999-2010	Fuel Saved 1999-2010
	Power	Water	Power	Water	Fuel		
Year	Fe	Fw	kJ/kWh	kJ/m^3	TJ	TJ	TJ
1999	0.8972	0.1028	14,776	95,263	288,325	288,325	0
2000	0.8971	0.1029	14,289	92,127	315,058	304,686	10,371
2001	0.8908	0.1092	14,276	92,041	339,963	328,468	11,495
2002	0.8781	0.1219	14,073	90,732	370,637	353,009	17,628
2003	0.8687	0.1313	13,843	89,247	393,088	368,265	24,823
2004	0.8573	0.1427	14,218	91,667	416,129	400,424	15,705
2005	0.8426	0.1574	14,407	92,886	445,810	434,688	11,122
2006	0.8608	0.1392	12,845	82,812	549,051	477,291	71,760
2007	0.8741	0.1259	11,589	74,715	652,333	511,628	140,705
2008	0.8656	0.1344	11,657	75,152	658,011	519,104	138,908
2009	0.8698	0.1302	11,561	74,535	724,433	566,808	157,625
2010	0.8859	0.1141	11,032	71,126	833,009	621,950	211,059
						Total	811,200

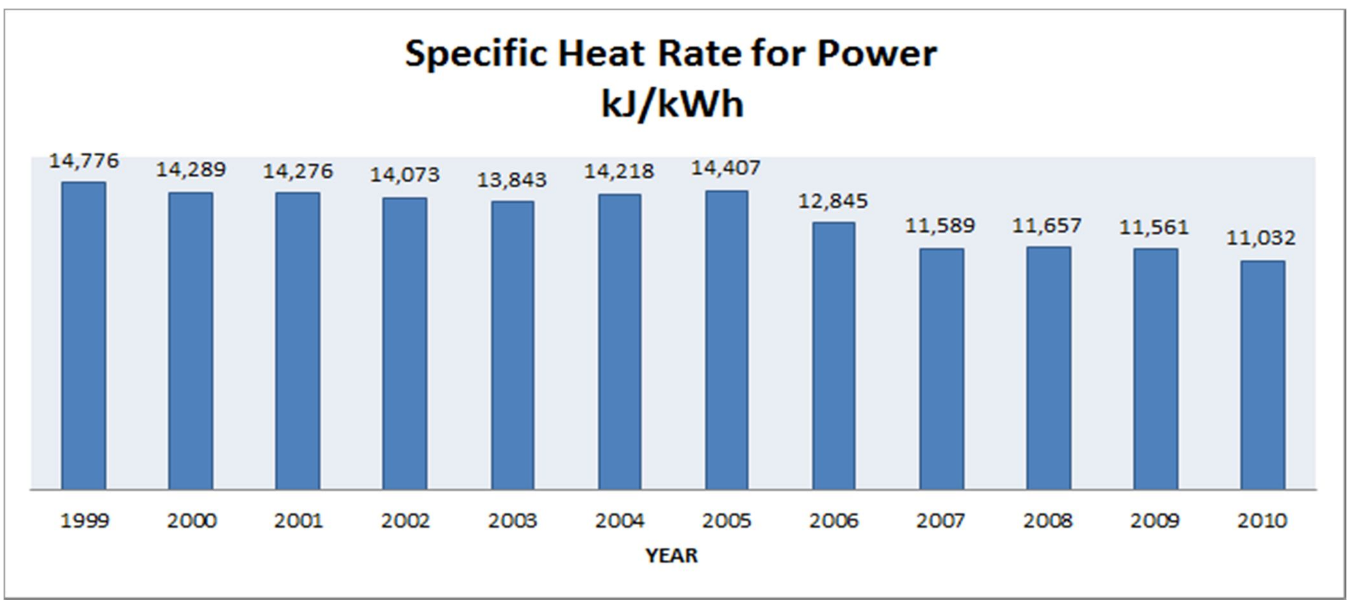

Figure 4. Comparison of Specific Heat Rates for Power Generation,1999–2010.

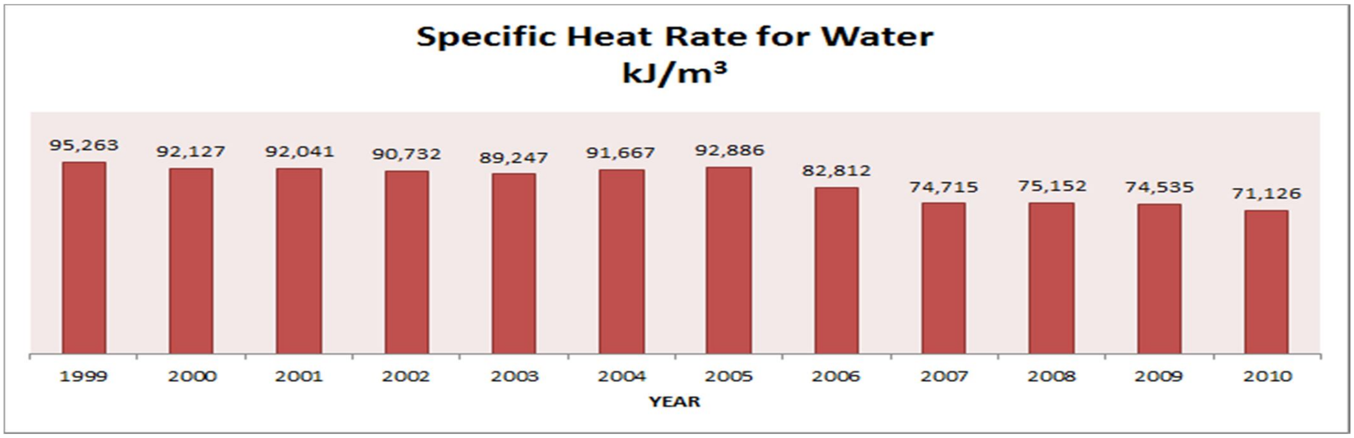

Figure 5. Comparison of Specific Heat Rates for Water Production,1999–2010

4.3 Emissions Reductions

The recorded fuel savings came with a concurrent reduction of emissions. The average emission factor for 1999–2010,calculated using IPCC tier 1 default emission factors and the average fuel mix, was 56.583 tCO_2/TJ. The reduction in emissions during the same period was 45,900,230 ton (Table4).

Actual yearly emissions increased from 16 to 35 million ton with a commutative increase of 115.7%. Emissions from power generation increased by 112.9%, and those from water production increased by 139.57%.Abu Dhabi's population growth is the main factor driving the increased consumption of both power and water. The average annual population growth from 1995 to 2005 was 4.4%; during 2005–2011 it was 7.7% [14].Per-person emissions also increased: from 14,797 to 17,354 kg/person, a rise of 17% (Table5). The separate results for power and water show that power generation is the main contributor to the emissions. The per-person figures highlight the extent of each consumer's contribution to emissions through their use of water and electricity.

Table 4. Average Fuel Mix and Carbon Emission Reductions from 1999–2010

from 1999 - 2010 Overall Fuel Savings achieved :	Fuel Type	Contribution to Fuel Mix	Fuel Saving (TJ)	CO_2 Emission Factor (tCO_2/TJ)	CO_2 Saved (Tons)
Distributed to	Gas	97.29%	789,188	56.1	44,273,466
Distributed to	CO	1.48%	11,978	73.3	877,996
Distributed to	DO	1.04%	8,438	74.1	625,232
Distributed to	FO	0.20%	1,596	77.4	123,537
Savings		13.55%	811,200	56.583	45,900,231

Table5. Yearly Carbon Emissions, numbers in tons (or kg)are CO_2equivalent from Water and Electricity Use.

CARBON EMISSIONS OF POWER AND WATER PRODUCTION					
	Power	Water	Power	Water	Total
Year	Tons	Tons	kg/Person	kg/Person	kg/Person
1999	14,637,593	1,676,718	13,276	1,521	14,797
2000	15,466,003	1,774,104	13,488	1,547	15,035
2001	16,555,516	2,030,206	13,883	1,702	15,585
2002	17,539,362	2,435,001	14,142	1,963	16,106
2003	18,102,403	2,735,200	14,035	2,121	16,155
2004	19,423,138	3,234,075	14,480	2,411	16,890
2005	20,725,449	3,870,561	14,809	2,766	17,575
2006	23,247,959	3,758,660	15,424	2,494	17,918
2007	25,306,069	3,643,444	15,589	2,244	17,834
2008	25,424,021	3,948,479	14,542	2,258	16,801
2009	27,895,858	4,175,882	14,815	2,218	17,033
2010	31,174,938	4,016,944	15,373	1,981	17,354

5. CONCLUSIONS

Abu Dhabi's energy reforms and effective regulation have led to significant improvements in energy generation and water production. Government action to improve energy efficiency could previously stimulate only individual projects, whereas effective regulation and market-based incentives can now encourage a variety of energy efficiency projects. The water and power systems are changing in terms of the fuel mix, their underlying technologies and the widening transmission network interconnections. Renewable energy generation, waste-to-energy projects and nuclear power plants are also being added to conventional fossil-fuel-powered projects. To achieve energy security, alternate fuel sources (e.g., liquefied natural gas), additional pipeline exports, further network interconnections and the export and import of water and/or power are potential actions. These developments have potentially significant effects on the development and optimized operation of the sector. They require further research to assess their long-term impacts on power and water production costs and emissions.

Acknowledgment

The authors declare that they have no conflicts of interest in this research.

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