Article

Not peer-reviewed version

Diffusion of Household Water Conservation Technology in a Gulf State: Implications for Water and Energy Demand

Hamad J. Alazmi * , Gordon Mitchell , Mark A. Trigg

Posted Date: 27 March 2026

doi: 10.20944/preprints202603.2239.v1

Keywords: household water demand; backcasting; technology scenario; diffusion of innovation; microsimulation; micro-component model; water conservation; Kuwait

 doi:10.20944/preprints202603.2239.v1

Article

Diffusion of Household Water Conservation Technology in a Gulf State: Implications for Water and Energy Demand

Hamad J. Alazmi [1,*], Gordon Mitchell [2] and Mark A. Trigg [3]

[1] Assistant Professor, Department of Geography, Faculty of Arts, King Faisal University, Al-Ahsa 31982, Saudi Arabia
[2] Associate Professor, School of Geography and water@leeds, University of Leeds, Leeds LS2 9JT, UK
[3] Professor, School of Civil Engineering and water@leeds, University of Leeds, Leeds, LS2 9JT, UK
* Correspondence: halazmi@kfu.edu.sa

Highlights

- Three technology-based scenarios have been developed to reduce household water demand in Kuwait.
- Diffusion of innovation approach has been used to systematically explore the potential of technology-based scenarios in reducing water demand.
- Micro-component model was applied in scenario model which has shown the ability to investigate water demand reduction pathways in a disaggregate manner.
- Technology-based scenarios have shown the ability to sharply reduce water demand in the household sector without change in consumption behaviour.

Abstract

Since 1970 there has been sustained growth in Kuwait's water demand, met by supply-side management associated with adverse economic and environmental implications. Demand side management is critical to a sustainable water future but removing subsidies is constrained by political realities. Therefore, this study explores the potential of technology-based conservation measures, addressing seven household water uses, in reducing demand. A population microsimulation coupled with a water micro-components model is used to forecast demand to 2050, which with its growing population, increases 32%. Demand is then 'backcast' against a 2050 'no new water' target, and two progressively more challenging targets. The technology transition pathways that emerge reveal the potential of technology measures, including that the 'no new water' target could be achieved just through targeting household showering, so long as near universal uptake of water efficient showers can be achieved. Doing so would deliver major reduction in water production cost and carbon emission from desalination. Although technology-based measures are likely to be more politically acceptable than pricing measures, the social acceptability of efficient devices, and the risk of rebound effect is not known, particularly with respect to the relatively small group of citizens in villa dwellings that account for 70% of demand.

Keywords: household water demand; backcasting; technology scenario; diffusion of innovation; microsimulation; micro-component model; water conservation; Kuwait

---

1. Introduction

In recent decades population growth, socioeconomic development, and climate change have caused dramatic increases in water demand in many parts of the world, with up to 4 billion people vulnerable to water scarcity at some places and sometimes (Gleick and Cooley, 2021). Freshwater shortage and misuse threaten both the environment and economies (Pahl-Wostl, 2007). In arid environments overexploitation of groundwater has led to falling water tables, water-quality degradation and ecosystem damage (Flavin, 2008) with demand satisfied by costly desalination which adds to energy demand and carbon emission.

Of the freshwater available on earth (3% of all water) only 0.4% can be accessed by the global population (Jern, 2006), and of this portion only about 0.3% occurs in the Middle East and North Africa (MENA), considered the driest region in the world (Dabour, 2006). The MENA region is expected to fall below the absolute water scarcity threshold of 500 m^3 per person per year by 2030 (de Waal *et al.*, 2023) yet in the Gulf Cooperation Council (GCC) sub-region, it has some of the highest levels of water demand anywhere (Al-Zubari *et al.*, 2017). GCC countries have previously neglected demand side management and maintain supply through desalination and over-pumping of groundwater, resulting in environmental impact, high energy use, and economic inefficiency (Odhiambo, 2016). Here, we take Kuwait as case study country of this hyper-arid region and investigate water conservation pathways for the household sector which accounts for over 65% of the total national water demand.

1.1. Water Resources in Kuwait

The GCC region has a hot desert climate and typically is water stressed. Kuwait, in the north east, has the lowest natural freshwater availability per-capita of any GCC country (c. 2 m^3/yr^{-1}) and indeed in the world, placing it far below the Falkenmark 500 m^3/capita/year absolute water scarcity threshold (Aleisa and Al-Zubari, 2017). Paradoxically its per capita consumption (PCC), at about 490 litre/day (l/d) (179 m^3/yr^{-1}) is amongst the highest anywhere (EPA, 2012). In 1970, demand was below 115 l/d per capita, but sustained growth means household demand is now 833 MCM yr^{-1} (MEW, 2022), and there are plans to boost water production to 1650 MCM yr^{-1} by 2035 to meet anticipated demand (Aburgubah, 2023).

The main drivers of such high consumption have been, first, an average annual population increase of 4.1% since independence in 1961, resulting in a doubling of population every 4.5 years (PACI, 2022). Second, Kuwait's development as a petrostate has been accompanied by industrialisation and urbanisation, with great wealth supporting more consumptive lifestyles. Escalating water demand has been met by desalination and over-pumping of groundwater, such that the withdrawal rate of 255 MCM yr^{-1} is roughly 12 times the annual groundwater inflow (Mabrok *et al.*, 2022). The first desalination plant in the GCC was Kuwait's Shuwaikh plant, commissioned in 1951 (Hamoda, 2001). Kuwait now has eight desalination plants (Figure 1) and is one of the most reliant countries on the technology. Nationally, desalination is the primary water source, accounting for 97% of total household water demand (Ismail, 2015), with investment in further capacity planned to meet demand to 2035 (Aburgubah, 2023).

Supply side augmentation has been the default water resource policy for decades with desalination capacity growing alongside population (Figure 2). Currently, there is about 1130 MCM installed capacity, following an increase of 37.3 percent from 2015 to 2020 as the Zour North desalination plant was fully commissioned in 2016, and capacity at the Doha West plant increased 46 percent in 2019 (MEW, 2022). Augmenting water supply in this way is current policy to meet anticipated growth in demand, particularly considering the substantial planned new urban areas. However, the approach is unsustainable, given the adverse economic and environmental impacts.

 doi:10.20944/preprints202603.2239.v1

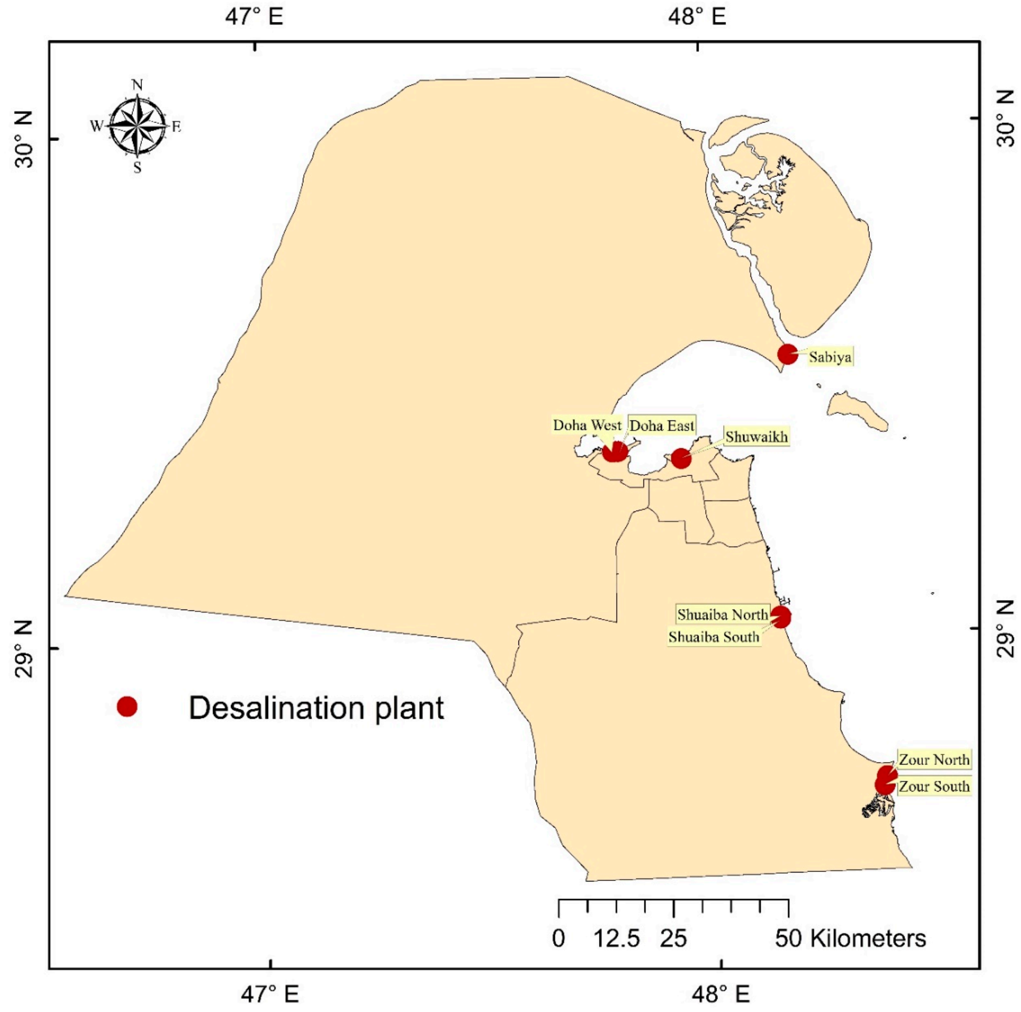


Figure 1. Desalination plants distribution.

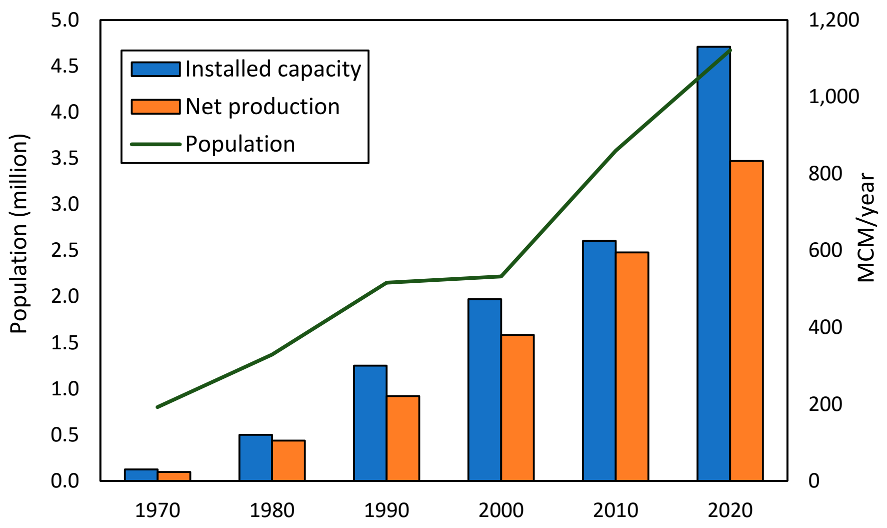


Figure 2. Desalination capacity and production against population growth. Source: Hamoda (2001); Al-Zubari et al. (2017); MEW (2022).

1.2. Economic and Environmental Impacts

High water demand has brought negative economic consequences as the state generously subsidises household water consumers. A flat volumetric tariff was introduced in the early 1960s and has not changed since. Consumers pay 0.58 US$ per m^3 of desalinated seawater well below the 3 US$ per m^3 cost (comprising 2 US$ per m^3 to produce and 1 US$ per m^3 to distribute) (Fadlelmawla, 2009). The subsidy of over 80 percent means the water supply system operates far below full cost recovery and represents a major fiscal burden for the government, which will grow as desalination production 2020-35 is planned to increase by 39% (Shaker, 2015). Desalination now accounts for 400 million barrels yr^{-1} of oil, 40% of Kuwait's oil production (Al-Jazeera, 2023), with this share expected to rise to 50% by 2050 (Al-Rashed and Akber, 2015). A further 20% of oil production goes to generation of electrical power, which is also heavily subsidised (Naseeb *et al.*, 2022). These subsidies are characteristic of a 'super rentier state' economy that depends on revenue from oil extraction, with both taxation and political representation largely absent (Siderius *et al.*, 2019). A consequence of this political model is the risk that expenditure increasingly outstrips the volatile revenue stream, and that opportunities to invest in other public infrastructure services are constrained. In Kuwait, significant budget deficits have arisen in recent years (23.2 percent of GDP in 2020, (CBK, 2020)).

Dependence on desalination also has detrimental environmental effects. Discharge of hypersaline effluent raises seawater salinity 5-10 parts per thousand (Lattemann and Höpner, 2008), raises temperature 7-8°C and lowers dissolved oxygen, and pollutes with chlorine and un-ionized ammonia (Jones *et al.*, 2019). These discharges can be fatal to marine life (Mezher *et al.*, 2011). Kuwait invests heavily in thermal distillation technology which produces about 4 m^3 of brine per m^3 of freshwater produced, compared to about 1.5 m^3 for membrane based desalination (Moossa *et al.*, 2022). This energy intensive desalination contributes significantly to Kuwait ranking third globally in terms of CO_2 emissions per capita (25.2 tonnes per capita yr^{-1}) (Al Hashemi *et al.*, 2014), well above the OECD's 9.5 tonnes per capita yr^{-1} and 8.9 tonnes per capita yr^{-1} for the EU (OECD, 2021). Reducing water demand is therefore critical to carbon emission reduction and to Kuwait meeting its ambition of carbon neutrality by 2050 (Reuters, 2022).

1.3. Demand Management Policies

Kuwait's policymakers and planners recognise, of course, that measures to reduce water demand are essential (Salim and Alsyouf, 2020). However, demand management is frequently argued as a technical problem only requiring leakage reduction or improving efficiency of agricultural water use (see e.g., Aliewi *et al.*, (2017)). Such measures offer benefits, but Kuwait already performs well in these respects relative to the wider MENA region (World Bank, 2017). For example distribution network leakage is 7% - 15% compared to 20% - 40% in the wider GCC (Al-Khalid *et al.*, 2013; Al-Zubari *et al.*, 2017) so benefits of further action here would likely be modest.

The transition to water security thus also requires demand management in households. This could be addressed by water pricing reform, adoption of water efficient appliances, and education, such as water use awareness campaigns, but these approaches vary greatly in terms of current feasibility. Although the price of water has not changed since the early 1960s pricing reform is politically sensitive, as heavy subsidies for essential commodities are used, as in many MENA states, to transfer resource rents to citizens (in the absence of social welfare safety nets) and so promote political stability. Cutting water subsidies for Kuwaiti citizens (expats may be treated differently) would require new legislation approved by at least two thirds of the National Assembly. Also, Kuwait has already had extensive water conservation campaigns and customers are aware of water scarcity, yet this awareness has not translated into customer engagement (Ali-Aljamal et al., 2020). Educational measures are thus not seen as a primary route to demand reduction but do have scope to complement other tools, whether pricing and/or technological.

Technological intervention is often employed in demand management due to its effectiveness (Stavenhagen *et al.*, 2018), with demand reductions of 30% - 50% achieved in the residential sector (Roccaro *et al.*, 2011; Liyanage and Vishwanathan, 2020). Therefore, given the challenges faced by water pricing and educational policy options in the GCC, we focus here on the uptake of water efficient appliances and domestic fittings. We model the impacts on demand of household water technology uptake scenarios, and evaluate the wider benefits, in terms of reduced desalination expenditure and carbon emission that could be achieved. In doing so we provide insights for officials and policymakers in Kuwait and the wider GCC region on the potential of water conservation technology for reducing water demand in the household sector.

2. Methods

2.1. Modelling Approach

The modelling approach has three phases. Phase I (section 0) developed a household water demand forecast to 2050 under a business-as-usual (BAU) scenario. Microsimulation was used to develop a spatially disaggregate forecast of household characteristics which were then combined with Per Household Consumption (PHC) values obtained from surveys, and constrained by national population projections, to forecast aggregate household water demand. Phase II (section 0) developed a micro-component (MC) model of PHC and per capita water consumption (PCC) and projected this model to the BAU aggregate forecast, to reproduce a forecast with greater functional resolution, where PHC consumption is calculated by addressing each household end-use component (e.g., shower) and its Ownership (presence) - Volume (per use) -Frequency (of use) (OVF) elements. This MC-OVF approach has resulted in a micro-component/water efficiency calculator (MC-WEC), embedded in a demographic model, with the integrated model used in Phase III (section 0) to explore water efficient technology diffusion scenarios.

In the technology-diffusion modelling phase, three aggregate water use targets for 2050 were established with reference to water policy debate for the region, and technology diffusion rates were then manipulated in the integrated model to meet the targets. The study thus uses the backcasting or 'soft path' approach that seeks to identify transition pathways, as opposed to conventional forecasting which would predict water use given a series of inputs (Dreborg, 1996). Three targets were investigated for 2050. First, "*No new water*" represents no increase in water supplied relative to a 2018 baseline (Brooks *et al.*, 2009). Whilst this scenario is merely 'no new water' it is nevertheless an ambitious target given the expected population growth, and if achieved would ensure water stress in Kuwait was no worse than it is now. To meet this target, demand reduction to 2050 must be circa 1% per annum (32% in total). "*Strong demand reduction*" is a much more demanding target based on an agreed target for Qatar (Baalousha and Ouda, 2017), and requires a 2% demand reduction per annum (64% in total). "*Modest demand reduction*" is an intermediate target averaging 1.5% demand reduction per annum (48% in total).

In modelling the technology scenarios, the Diffusion of Innovation (DOI) approach was used which allowed a systematic exploration of rates of uptake and market penetration of each micro-component, represented by a Gompertz (sigmoid) function. Water demand under the most feasible technology diffusion pathway for each backcast target was then compared with BAU demand forecasts and the economic (desalination) and environmental (CO_2) costs calculated (section 0).

2.2. BAU Demand Forecast to 2050 Using Spatial Microsimulation

The first step in developing a BAU demand forecast to 2050 was to reproduce observed household demand, which is only known in aggregate, for a baseline (2013–18). This process used household-scale microsimulation which overcame several data limitations and provided a means to quantify demand at the household level and a basis to later apply the micro-component (OVF) model. In 2013 the Central Statistical Bureau (CSB) surveyed water demand in 2,961 households across all Kuwait's governates, with representation of household size, household status (Kuwaiti citizen, non-Kuwaiti/expatriate – mostly domestic workers), and dwelling type (villa, floor or apartment in a villa, apartment, traditional house, or annex which is only occupied by non-Kuwaitis). This disaggregate (per household consumption) demand is recorded in the resulting 'PHC demand matrix'. Because of

 doi:10.20944/preprints202603.2239.v1

the survey size, not all possible combinations of matrix variables (e.g., size/dwelling type) are represented in the original survey, so the matrix has some missing values. These were imputed using non-linear power functions.

The PHC demand matrix was then scaled to the national population using census data for 2007–18 obtained from the Kuwait Public Authority and Civil Information (PACI). This 'household population matrix' includes household size and household status by governorate but lacks the dwelling type variable of the PHC demand matrix, recorded in the CSB survey, and which is an important influence on demand. This problem was addressed using a synthetic population microsimulation that constructs an artificial population with a distribution of characteristics that matches that in the observed population and enables estimation of variable combinations that do not exist in the census data. In effect, synthetic population simulation can reproduce the characteristics of a population allowing extension from a sample to an entire population, thus overcoming data limitations.

This process enabled the aggregate observed baseline water demand to be reproduced, but now with a model that is disaggregated by characteristics of the household, dwelling and geography. The final step in producing the BAU forecast to 2050 was to apply this model to a national population projection. In this step, a population projection was adopted from the Techno-Economic Division of the Kuwait Institute for Scientific Research (TED/KISR). The projection uses a cohort ageing model with a representation of births/deaths and immigration/emigration, which has the same data structure as the PACI-derived matrix above. As only a single population projection was available from TED/KISR we conducted a series of sensitivity tests to establish a central water demand projection. The results show a 45% increase in demand 2019-2050, to 664.1 MCM. Full details of the baseline demand forecasting are given by (Alazmi *et al.*, 2024).

2.3. Micro-Component Modelling

Herrington and Britain (1996) describe the micro-component approach which they conclude is key in controlling household water demand. The approach is also known as the OVF approach, referring to the Ownership of a water use component (O), water demand per component use (V, Volume) and Frequency of use (F), and can be described in terms of market penetration in the household sector (McDonald and Mitchell, 2013; Browne, 2015). The micro-component approach offers scope for reduction in household demand without change in consumption behaviour, through technical measures and adoption of more efficient water appliances.

To date, five observational micro-component studies of water use have been conducted in Kuwait (Mukhopadhy *et al.*, 2001; Al-Humoud and Al-Ghusain, 2003; Al-Humoud and Jasem, 2008; Burney *et al.*, 2017; Aliewi and Alayyadhi, 2018). These mostly ignore non-Kuwaiti/expatriate households that comprise about 70% of the national population, pay limited attention to indoor vs outdoor use, and do not break individual micro-components into their constituent OVF elements. None provide a comprehensive analysis of MC household use, hence our MC modelling faced data limitations that needed to be overcome.

MC data from KISR Water Research Centre (WRC/KISR) acoustic flow monitoring is reported by (Aliewi and Alayyadhi, 2018). These data give a MC breakdown (as % of a households total water use) and as the most resolved MC data for Kuwait, addressing seven MC's, provide our "base model" (Table 1). Unusually, outdoor use is included, but the data only addresses Kuwaitis in villas (houses), so neglecting non-Kuwaitis that live in villas, Kuwaitis that do not, and the large number of non-Kuwaitis who mostly live in flats. In the absence of this data, we assumed that WRC/KISR MC observations were applicable more widely, with adjustments to reflect outside water use. Thus, we assume that, all else being equal, toilet flushing in non-Kuwaiti households (for example) is comparable to that in the Kuwaiti households (villas). Given common factors, such as the very low price of water paid by all, such assumptions are not unreasonable, but further MC data would clearly be valuable.

Table 1. The base micro-component model and derivatives.

Micro-Component	**Base model** (% total demand)	**1st derivative** (% total demand)	**2nd derivative** (% total demand)
Population segment model applies to	All households in villas with garden	All Kuwaiti households, and 90% non-Kuwaiti households	10% of non-Kuwaiti households
Shower	61.03	62.30	63.68
Toilet	9.63	10.90	12.28
Washing machine	3.33	4.60	5.98
Dishwasher	2.23	3.50	4.88
Washing Floors	10.52	11.80	13.18
Car Washing	5.63	6.90	Excluded
Garden/lawn Irrigation	7.63	Excluded	Excluded
Total	100	100	100

To adjust for outside use the garden/lawn component (hosepipes are banned and only drip or spray irrigation is permitted) was applied uniformly to 46.7% of both Kuwaiti and non-Kuwaiti households in villas, based on WRC/KISR observations. The car wash component was applied to all Kuwaiti households, and for non-Kuwaiti households, to all those in villas, and to 90% of households in other dwelling types, as only 90% of non-Kuwaiti households in other dwelling types own cars. Thus, two variants of the base model have been derived, one excluding the garden/lawn watering, the other additionally excluding car washing (Table 1). For both derivatives, the micro-components remaining after external use components have been excluded have their water use share scaled upwards with equal weight until 100% of water use is accounted for. The base MC model thus has all seven micro-components but applies only to villas (Kuwaiti and non-Kuwaiti) that have gardens/lawns. The first derivative (garden/lawn exclusion) was applied to all Kuwaitis and non-Kuwaitis in villas without a garden/lawn, plus all other Kuwaiti dwelling categories, and 90% of the non-Kuwaiti households in other dwelling types. The second derivative (all outdoor water use excluded) was applied to 10% of non-Kuwaiti households in non-villa dwellings (i.e. the non-car owners).

The Table 1 micro-component data (% share of demand by MC) was then applied to the earlier household level forecast (litres/day) to estimate litres/day per MC in all the households modelled (by household size, type and citizen status) with demand reported as PHC per MC. These MC values were then used to derive OVF values (whose product matches the modelled MC use) to enable subsequent investigation of uptake of more water efficient household technology. To do this the reported flowrate/volume (V) for each traditional appliance use was collected from several markets that export water use appliances to Kuwait (Kuwait imports all such appliances) (see Table S1). Frequency of use (F) data was derived from the WRC/KISR study – these data are not normally distributed, hence we adopt median rather than mean values in the MC model (Tables S2 and S3). A model fitting exercise was then conducted by using linear equations, as:

$$f(y) = xb + a\ (xb) - x \qquad (1)$$

Where: y is the dependent variable (MC water use in litres); a is the duration of component use in minutes; b is the flowrate/volume (V) of a MC traditional appliance in litres per minute, and x is the median frequency (F) of use per day or week and is constant across all components. This equation was applied to all those components with duration of use, flowrate/volume, and frequency of use parameters (showering, washing clothes; floor washing; hand dish washing; car washing and

 doi:10.20944/preprints202603.2239.v1

garden/lawn irrigating). A second equation was applied for dishwashers and washing machines where duration of use is not relevant:

$$f(y) = x + b\ (x) - x \tag{2}$$

Where: y is the MC water use; x is the frequency of appliance use per day; and b is the water use per load. In Kuwait, washing machines are universal but only 2.9% of Kuwaiti households, and 1.2% of non-Kuwaiti households, have a dishwasher. Note that in fitting MC estimates to the BAU forecast, only the V and F elements are imputed to reach the given demand. Technology ownership (O) is not modelled and, excepting for dishwashers, we assume all households have the relevant appliances. Figure S1 shows an example of the developed MC-OVF-WEC model.

The full integrated model was applied for the BAU forecasting period, with the OVF values held static, and the demand increases being demographically driven. This model acts as the baseline to explore the effect of manipulating OVF values, and particularly the effect of raising the efficiency (V) of household water technologies and fittings, using a diffusion of innovation (DOI) approach.

2.4. Diffusion of Water Efficient Household Technologies

Diffusion of Innovation (DOI) theory attempts to explain the spread of ideas or technology in a population. Rogers, who popularised the theory from the 1960's, describes it as "a process in which an innovation is communicated through certain channels over time amongst members of a social system" (Rogers 2010, p. 5). The number of new adopters over time follows a bell curve, where the initial rate of adoption is low (Innovators) then grows rapidly before the adoption rate declines, with the last adopters (Laggards) occurring near saturation (Figure 3). The cumulative uptake displays an S-shaped Gompertz curve which is the adoption trajectory we apply to represent the uptake of more water efficient technology in Kuwait's households to 2050.

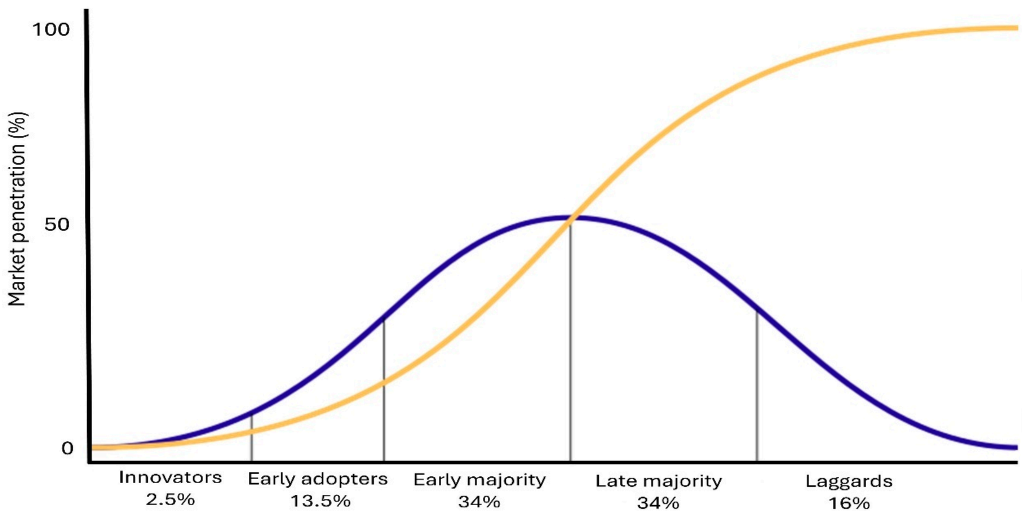


Figure 3. Innovation diffusion. Modified after Rogers (2002).

We apply a DOI approach in the integrated model to represent the uptake of more water efficient appliances in the Kuwait population to 2050. Frequency of use (F) is fixed in the water calculator, and water efficiency improvement is addressed by manipulating the O variable to reflect the gradual replacement of current household technology with more efficient (lower V) technologies. For example, we assume that all households have toilets and model the effect of these gradually being replaced by more efficient lower flush models. To identify suitable V values we collated performance data from manufacturers on household water use technologies that are marketed as water efficient (Table S4; see (Alazmi, 2022) for further details). For each micro-component reported water use performance values followed a normal distribution, from which we defined 'efficient' as any value from mean and above (noting that all the appliances included were considered efficient), and 'highlyefficient' as any value below the mean (Figure 4). It is these values that were systematically manipulated, alongside technology uptake rates in population segments, to meet the aggregate 2050 water use targets.

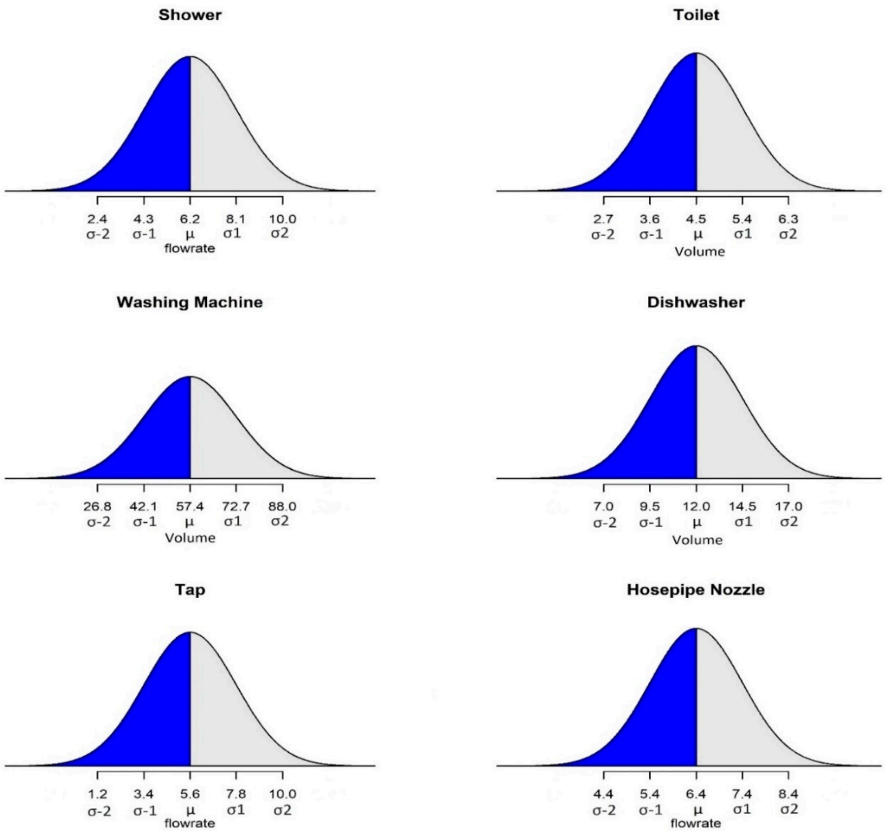


Figure 4. Distribution of volume (litres per cycle) and flowrate (litres per minute) in efficient and high-efficient appliances.

The uptake of more efficient technology to households was addressed using a Gompertz function (Waliszewski and Konarski, 2005) defined by parameters of adoption rate (for a micro-component of given efficiency), penetration rate (total uptake by population by 2050), and time. Adoption rate, k, is expressed as;

$$k = \frac{n_t}{N_t} * 100 \quad (3)$$

Where n denotes the household population adopting a given technology for a given year t, and N refers to the total household population for a given year in the scenario horizon t. The penetration rate p is expressed as;

$$p = \sum_{t=0}^{31} tk \quad (4)$$

Where t is years elapsed from the 2019 base year; and k is the adoption rate. Using these equations, a Gompertz function can be used to model the technology uptake and penetration (DOI curve), as follows:

$$p_t = p_0 \exp\left(r/\lambda\{1 - \exp(-\lambda t)\}\right) \quad (5)$$

 doi:10.20944/preprints202603.2239.v1

Where p_t is the penetration rate in the household population segment adopting a certain technology at time t; p_0 is the value of penetration rate at time zero (2019); r is a constant determining the maximum value of p that can be reached; and λ is a constant determining the rate of growth of the curve. The constant r can be manipulated to represent the total market penetration of water efficient technology needed to meet the aggregate household water use targets set for 2050.

Using this approach numerous technology adoption scenarios can be explored by manipulating the technology mix (efficient and high-efficient), technology introduction year (sooner or later), and uptake/penetration rates (low or high). The choices made then reflect the transition pathway required to meet the three aggregate 2050 water use targets. Due to the profusion of possible model tests, we limit our presentation to the three adoption scenarios (one for each of the 2050 targets) that we felt were most feasible, and which reflect conservative to aggressive demand reduction through household technology. For our *No new water* target, we focus on shower efficiency to achieve the 2050 target, as this micro-component accounts for over 60% of all household demand. Shower replacement is also relatively easy and has been the main target in household demand management actions elsewhere (e.g. the USA EPA legislated in 1992 to replace traditional showerheads with more efficient ones). A focus on showers can also demonstrate to policymakers the benefit possible from promotion of a simple technological change. For the *Modest demand reduction* target, a mixture of efficient and high-efficient appliances is selected for the Shower, Toilet, and Washing Floor components, as these occupy the highest proportional demand distribution (> 80%) in the MC model. For the *Strong demand reduction* target, we selected a high penetration rate of high-efficiency technology across all micro-components, thus demonstrating to policymakers a potential technology pathway to aggressive demand reduction, and then benefits that may then follow.

3. Results and discussion

3.1. Household Water Demand in BAU and Technology-Based Scenarios

<u>BAU scenario:</u>

Household demand increases from 463.5 MCM in the 2019 base year to 664.1 MCM by 2050 (Figure S2). The annual increase rate ranges from 1.8% in 2020 to 0.6% in 2050, with an average of 1.15% yr^{-1}. For Kuwaiti (citizen) households, demand increases from 345 MCM in 2019 to 503.1 MCM in 2050, an increase of 31.5%, with annual increase ranging from 1.75% in 2020 to 0.75% in 2050 (average 1.2% per annum). For non-Kuwaiti households (migrant worker and expatriate families), demand increases from 118.4 MCM in 2019 to peak at 160.4 MCM in 2048 followed by a decline to 160.1 MCM in 2050, because of a decrease in non-Kuwaiti population. Non-Kuwaiti demand increases 26% overall (average 0.97% per annum), with the annual increase rate ranging from 1.88% in 2020 to -0.12% in 2050. The relative share of total demand is largely constant, with Kuwaiti's accounting for 74.42% of household demand in 2020, 74.26% in 2030, and peaking at 75.89% in 2050.

<u>No new water scenario:</u>

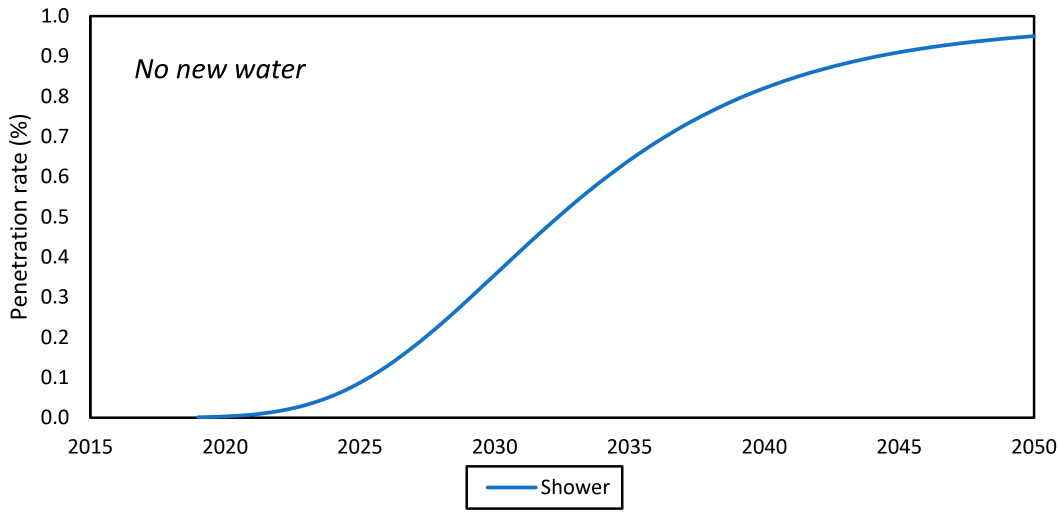
To meet the *No new water* target, demand must fall 32% by 2050 relative to BAU (average 1% per annum), offsetting the demand from a growing population. In our preferred *No new water* pathway, the required level of demand reduction relative to BAU can be achieved through adoption of more efficient (mean μ) showerheads alone, so long as adoption occurs across all household population segments with a 95% penetration rate by 2050 (Figure 5, Text S1 and Figure S3). This transition pathway may appear demanding due to the near saturation level of technology adoption required, and which requires adoption to reach 6.3% per year (in 2031), or about 60,000 households / 240,000 showers. However, headroom can be added by, for example, requiring the most efficient showers to be retrofitted in a particular population segment (e.g. Kuwaitis where demand is highest, or non-Kuwaitis if politically more feasible), and/or in all new dwellings, which would allow for lower rates of penetration overall. There are wider questions here of course, including around capacity to obtain and install the required fittings, and over technology rebound and regression (e.g. will some householders remove low flow showers if they are perceived to perform less well?). However, the key finding here, is that the substantial projected BAU increases in water demand to 2050 could be eliminated through just one technology change, if applied widely.

Modest demand reduction scenario:

This scenario has a deeper demand reduction target, equivalent to an average of 1.5% per annum, which is 48% per annum reduction relative to the 2050 BAU forecast, so gives a modest overall reduction. Achieving this requires the adoption of: (i) high-efficient showerhead (= -1σ) as above; plus (ii) efficient toilet; and (iii) floor washing tap appliances (= μ). MC-WEC model manipulation shows that to meet the target using these fittings requires a market penetration by 2050 of 88% for showerheads, 84.5% for toilets, and 75% for washing floor taps, assuming no differentiation between household population segments. Despite adding two new water micro-components in this pathway (toilets, taps) the penetration rates required are high, because showering accounts for such a large share of total household use (60%). Maximum required uptake rates peak in 2030 (Table S5, Text S2, Figure S4) and for showers are lower than the *No new water* pathway, indicating how making toilets and taps more efficient offsets some of the necessity to upgrade showers so quickly. Whilst high efficient toilets/taps can be made mandatory in all new housing, retrofit in existing housing will be required too. This is feasible using simple tap inserts (but which may be removed by users if the flow is deemed unsatisfactory) but toilet upgrades is a more substantial task, that may only naturally happen when bathrooms are remodelled (which also required that only water efficient sanitary ware can be purchased). However, there is scope to use cistern displacement devices to improve water use efficiently of older toilets. Typically, these can save 2 litres per flush.

Strong demand reduction scenario:

The deep reduction target is an average fall of 2% per annum, which is a 64% per annum reduction relative to the 2050 BAU forecast, a substantial overall reduction. To achieve this, it is necessary that all household population segments adopt high-efficient appliances for all seven micro-components, and with high penetration rates (Table 2. Measures and actions to achieve household water reduction targets for 2050, Table S5, Text S3, Figure S5). Uptake rates need to slightly exceed those required in the above scenarios, and for the remaining micro components must be between 2-6.3% by 2030. Naturally, if these uptake rates are not achieved until later in the backcast period, higher rates will be required closer to 2050. Note that whilst this is an aggressive demand reduction pathway, requiring substantial uptake of domestic water efficient technologies, reductions at the household level do not result in undue privation for households, because current per capita consumption is so high. A 64% reduction from a current a 500 litre/cap/day returns 160 litre/cap/day, which is still well above that of most developed countries.



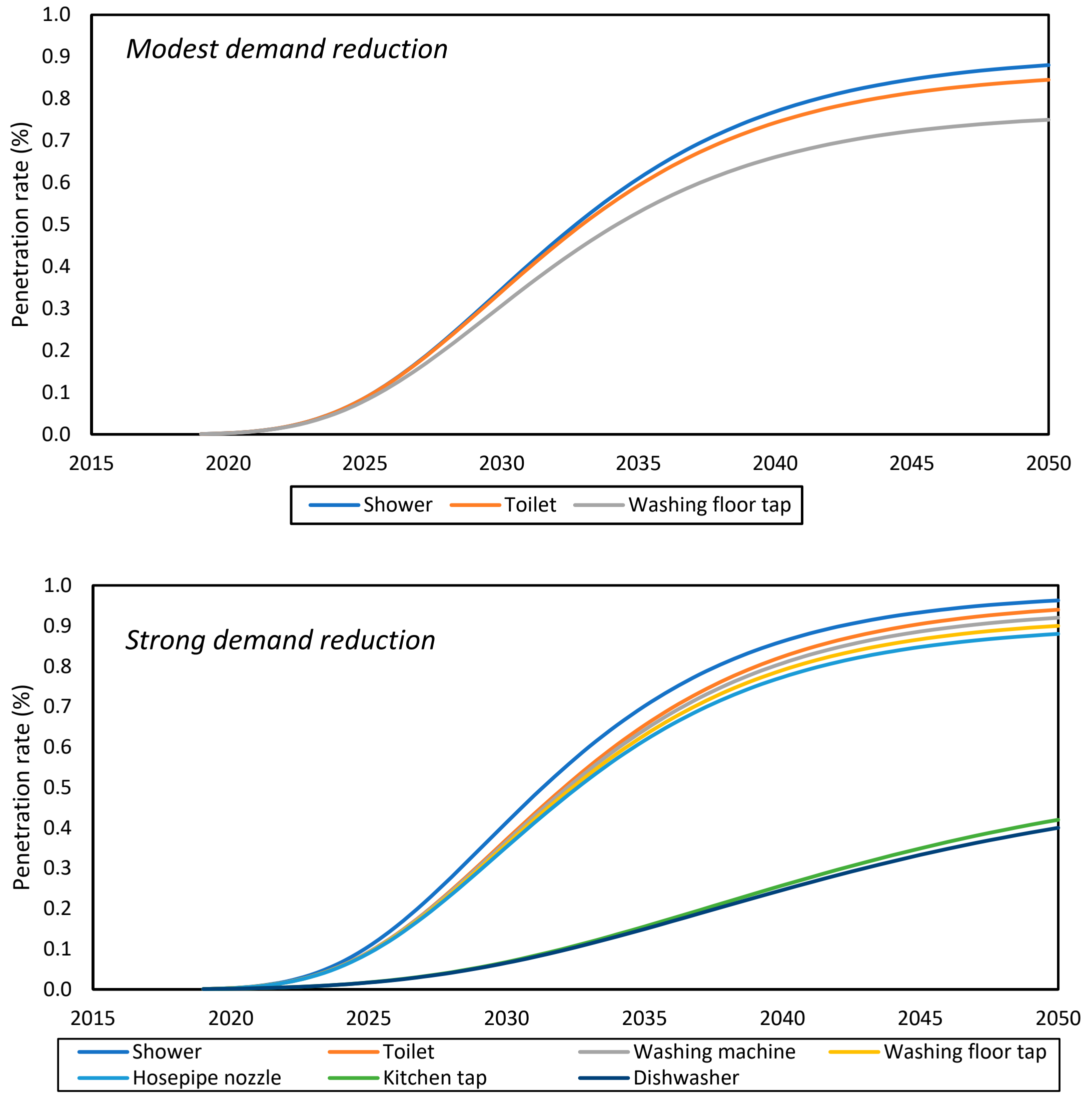


Figure 5. Market penetrations of innovative water appliances in technology scenarios.

3.2. Economic and Environmental Impact Assessment

To estimate economic costs and emissions, values of water production cost and revenue per m^3 (3.00 and 0.58 US$), and CO_2 emission (23.4 kg/m^3) were applied (Alazmi *et al.*, 2024) to the modelled water demand scenarios. Resulting values were nominal and not temporally discounted or otherwise adjusted.

3.3. Economic Appraisal

Under the BAU forecast, total (nominal/unadjusted) production cost increases from 1.39 billion US$ in 2019 to 1.99 billion US$ by 2050. This is an increase of 43.3% over the period, some 601.80 million US$, or about 19.4 million US$ per year. Annual cost increases range from 1.82% (2020) to 0.57% (2050). Revenue from water sales is 276.5 million US$ in 2019, rising to 389.1 million US$ in 2050, an annual average increase of 3.5 million US$. In terms of economic efficiency performance, total revenue is about 1.12 billion US$ below production cost in 2019, with this annual loss rising to 1.61 billion US$ in 2050. Loss from Kuwaiti households is 835 million US$ in 2019, rising to 1.22 billion US$ by 2050; whilst for non-Kuwaiti households, losses are 286.6 million US$ in 2019, rising to 387.3 US$ by 2050.

 doi:10.20944/preprints202603.2239.v1

In the *No new water* scenario, total (nominal/unadjusted) economic values naturally show little change as the intention is to keep future demand in line with the base year demand. Thus production cost decreases only a little, 60.31 million US$ by 2050 (from 1.38 billion US$ in 2019) and total revenue from water sales falls only 11 million US$ by 2050, from 268.6 million US$ in 2019. The bulk of these costs and returns are associate with the Kuwaiti population as they have a much larger share of demand than expatriates/migrant workers.

Under *Modest demand reduction*, total production cost decreases from 1.38 billion US$ (in 2019) to 1.03 billion US$ by 2050; a saving of 353.3 million US$. Cost increases are greatest early in the period (1.45 billion US$ in 2025) and least in 2050 (1.03 billion US$) when demand reduction has taken effect. Annual water revenue falls, from 268.6 million US$ in 2019, to 200.3 million US$ in 2050. However, in terms of economic efficiency (nominal revenue less cost), annual losses fall from 1.12 billion US$ in 2019 to 835.6 million US$ by 2050. Under the *Strong demand reduction* scenario, total annual production cost falls from 1.39 billion US$ in 2019 to 716.4 million US$ by 2050, and total annual water revenue falls from 268.5 million US$ in 2019 to 138.5 million US$ by 2050. In terms of economic efficiency annual losses fall from 1.12 billion US$ (2019) to 557.9 million US$ by 2050 (see Figure S6 for Kuwaiti non-Kuwaiti breakdown). Note that even under this very strong demand reduction scenario, cost recovery is not achieved with the current level of water subsidy.

3.4. Environmental Appraisal

Under BAU, total household CO_2 emission increases substantially with rising demand and desalination, from 10.85 to 15.54 Mt per annum (2019-2050), an average annual increase of 1.02%, equivalent to 151.4 Kt/yr. Kuwaiti households CO_2 emission increases from 8.1-11.8 Mt over the same period, and from 2.8 - 3.6 million tonnes for non-Kuwaitis (Figure S7), in line with the share of water demand. In the *No new water* scenario, total household CO_2 emission is largely steady as expected, falling just 15.1 Kt/yr (0.14% year on average) from 10.83 to 10.35 Mt by 2050. Kuwaiti household account for about 75% of all emissions during the period. Under the *modest demand reduction* scenario emission fall to 8.07 Mt by 2050, an annual reduction 0.78% (equivalent to 84.6 Kt/yr). Kuwaiti households emissions falls to 6.12 Mt in 2050, and that of non-Kuwaiti's to 1.95 Mt. Under the *Strong demand reduction* scenario, emissions falls to 5.58 million tonnes by 2050, an annual average decrease of 2.1% (equivalent to 5.25 Kt/yr).

3.5. Realising the Technology Scenarios

The feasibility of delivering nationwide adoption of water efficient technology in the household sector will be determined by a range of considerations and needs further analysis. However, we can identify several key considerations at this stage (Table 2). Institutionally, the technology adoption route is feasible as the legal hurdles are not substantial. Water use appliances are not classed as essential commodities in Kuwait, unlike critical infrastructure in water and electricity production, thus regulations affecting their use can be approved by the Minister for Commerce, and do not need approval of the full National Assembly. From an economic perspective, the benefits of demand control appear high, making it possible to offer subsidies for those upgrading to new more efficient water use appliances. For example, under the *No new water* scenario, total gross savings (to 2050) from the avoided desalination amount to about 0.66 billion $USD; if we assume the (approx. 1 million) showers were replaced at a cost of $500 each ($0.5 billion) then we get a sense of the possible benefit-cost ratio (BCR) of a technology-based household water efficiency programme. The scale of the likely BCR means that 100% grants could initially be offered to encourage technology adoption.

An issue here arises, however, in terms of having a sufficiently well-developed plumbing sector (particularly skilled labour and wholesale/retail supply of water efficient devices) to meet the implementation schedule. Currently it would be very challenging to install a large quantity of appliances quickly because Kuwait has a small plumbing industry with few trained installers. Our technology uptake scenarios follow a Gompertz curve and so there is no requirement to grow installation capacity overnight, but development of this capacity will be needed as the required

 doi:10.20944/preprints202603.2239.v1

uptake rate accelerates. For instance, in the developed scenarios, uptake rates accelerate to reach peaks in years between 2028 – 2032. The plumbing industry is dominated by non-Kuwaitis, whose continued presence in Kuwait is not guaranteed. To rebalance the population (70% are non-Kuwaiti expatriates) the government are changing labour laws, which could act to limit the capacity of the plumbing sector. For example, the government recently decided not to renew visas for expatriates over 60-years-old. Furthermore, due to the Covid-19 pandemic, 15% of the non-Kuwaiti population (c. 400,000 people) cancelled their residency and left Kuwait, or were deported, from 2020 to 2021. This has led to labour shortages, with wages increase for blue collar jobs and longer lead times for service, from weeks to months (CNBC, 2021).

In terms of public acceptability, technology-based water efficiency measures are considered much less problematic than demand management through price rises, as low prices for basic commodities (energy, water) are a key element of the country's social welfare policy. Thus, promoting efficiency through technology supports demand management without the challenge of major political reform. Nevertheless, public resistance to water efficient technology may exist, particularly if the level of service provided is perceived as inferior. For example, it is a relatively simple task to replace an aerating tap or remove a tap insert, so some erosion of water conservation savings is possible (this is a known issue in the water conservation field, but with little hard data). Investing in public education and outreach to raise water awareness and promote uptake may help to mitigate the impact of such rebound effects.

Table 2. Measures and actions to achieve household water reduction targets for 2050.

Scenario	Technology adoption proposal	Implementation actions needed	Feasibility
No new water	Focus on showering as the dominant water use component. Target adoption of water efficient showers in 95% of households by 2050 across all population segments.	Ban installation of low efficiency showers in new build dwellings; ban on sale of water inefficient showers in refurbishment market supported by rebates/subsidy for water efficient shower installation. Achieve installation at annual rate able to deliver 95% market penetration by 2050**Error! Reference source not found.**. Requires assessment and delivery of required plumbing workforce capacity.	Water use fittings & appliances are classed as non-essential goods so regulatory change can be made by the commerce minister without recourse to the National Assembly (parliament). Aggregate demand savings imply a high economic benefit-cost ratio, and scope to offer substantial subsidy drive water efficient appliance uptake. Limited capacity of plumbing workforce a constraint; could be addressed via importing skilled labour and/or skills training for Kuwaitis (political sensitivity re immigration policy).

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 March 2026 doi:10.20944/preprints202603.2239.v1

Modest demand reduction	Add high water use components to give, by 2050, 88% market penetration of high-efficient showers; 84.5% of efficient toilets; and 75% of efficient washing floor taps. Address all household population segments.	As above plus include toilets and taps in water efficiency fittings regulation. Expansion of plumbing workforce capacity, and extension of rebates/subsidy to the wider range of water efficient fittings.	As above plus growing risk of rebound effect / regression if consumers disapprove of technology performance
Strong demand reduction	Extend to full range of water use components to give, by 2050, 96.3% market penetration of high-efficient showers; 94% toilets; 92% washing machines; 90% washing floor taps; 88% hosepipe nozzles; 42% kitchen taps; and 40% dishwashers, for all household population segments.	As above plus extend water efficiency regulations to washing machines and dishwashers. Further expansion of plumbing workforce capacity, and extension of rebates/subsidy to cover all water efficient fittings.	As above

4. Conclusions

Kuwait faces a critical water future. It has the lowest per capita natural water resource globally, yet counterintuitively the highest per capita water consumption, only made possible through desalination, which takes a very high and growing share of national oil sale receipts. The desalination also contributes to Kuwait having one of the highest per capita CO_2 emissions in the world. Despite this, Kuwait has a growing water demand and lacks effective household water conservation , largely because water prices, which are far below full cost recovery, have historically been kept low as part of national welfare policy.

This study's findings show that without further intervention, household water demand will increase substantially, driven by strong population growth. Given the political challenge of water price rises, we assessed whether water efficient technology uptake could allow Kuwait to meet future water use targets, including a conservative 'no new water' target (with population growth) and two progressively more ambitious targets, that represent average per household/per capita demand reductions against business as usual of up to 64% per annum by 2050. An integrated model, applying a micro-component water model to population segments (defined by citizen/expat, household size, and dwelling type) modelled using microsimulation has allowed identification of technology uptake scenarios capable of meeting the 2050 water targets.

 doi:10.20944/preprints202603.2239.v1

The possible transition pathways (technology mixes, market penetration and uptake rates) are numerous, hence for each of our 2050 targets, we present here just one technologically feasible pathway. For each target, other pathways are possible. For example, we show that the *no new water* target can be achieved just by using efficient shower technology if 95% of households adopt, but other pathways exist, such as requiring all households to have a water efficient shower, or having a share of households adopting the most efficient shower technology, or extending the no new water measures to other micro components. Thus, our results do not define the only pathways that could be taken to meet the demand reduction goal but demonstrate the capability of water efficient technology in meeting 2050 water use targets.

Demand increases are most strongly driven by the Kuwaiti population (rather than expatriates) and by those households in villas. This segment accounts for a disproportionately large share of all household demand, over 70%, so targeting conservation measures here is a priority (we calculate that if all such households installed the most water efficient fittings for all micro components total demand could fall slightly over 70% relative to BAU). We note of course that there is scope for a rebound effect, whereby not all demand savings that are technically possible may be delivered as, for example, householders remove or replace water efficient fittings if they are unsatisfied with the performance. This is clearly an area in need of field work, but in this context it is worth stressing that per capita demand in Kuwait is exceptionally high, and a two thirds reduction would still result in a per capita demand well above that in most developed countries.

The study supports the conclusion that deep cuts in household water demand are technically possible without water price rises, through diffusion of water efficient fittings and appliances. Doing so can deliver substantial benefits, as desalination cost savings and carbon reduction, which may be greater/lesser than our estimates, depending upon the particular composition and timing of each technology transition pathway. The cost savings are however so large, that substantial subsidies could be offered to encourage and support uptake and retrofit of water efficient technology. Whilst introducing new regulations and perhaps subsidies to promote water efficient technology seems relatively straightforward, there are dangers in doing so if the installation capacity does not exist. The plumbing industry in Kuwait is currently underdeveloped, and staffed largely by expatriates, whose continuing residence in the country is certain. Thus, attention must be given to ensuring that there are sufficient skilled installers of water efficient devices, and sufficient supply of the technology, to meet the needs of the transition pathways. Whilst the value of the technology approach has been demonstrated, we also recognise that the price elasticity of household demand in Kuwait is negative and elastic in the long run (Alfalah, 2021), hence there is considerable value in pricing reform, such movement is made towards full cost recovery pricing. Such reform would be mutually beneficial in terms of driving technology adoption and developing the necessary small business capacity and implies that lower water efficient technology adoption rates are practicable. However, if any pricing reform remains politically unpalatable, policy to reduce demand in the household sector must focus on more aggressively driving adoption of water efficient technology through regulatory routes.

Acknowledgments: Thanks to Prof. Waleed Zubari, Department of Natural Resources and Environment, Arabian Gulf University for guidance on model evaluation and to Prof. Amjad Aliewi from WRC/KISR for providing the research team with the micro-component dataset.

References

Aburgubah, Mutlaq. 2023. Ministry to boost Kuwait water supply. *Kuwait Times*. 23 March.

Al-Humoud, J. and Al-Ghusain, I. 2003. Household demand for water: A case study in Kuwait. *Kuwait Journal of Science and Engineering*. **30**(1), pp.197-212.

Al-Humoud, J. and Jasem, M. 2008. Freshwater consumption in Kuwait: analysis and forecasting. *Journal of Water Supply: Research and Technology—AQUA*. **57**(4), pp.279-288.

Al-Jazeera. 2023. Kuwait plans to produce three million barrels of oil per day in 2025. *Al-Jazeera*. 18 June.

Al-Khalid, A, Al-Senafy, M and Azrag, E. 2013. Estimation of leakage from the freshwater network in Kuwait. *Water Resources Management VII.* **171**, p129.

Al-Rashed, M. and Akber, A. 2015. Water security in the Gulf Cooperation Council (GCC) countries: challenges and opportunities. *Proceedings of the International Association of Hydrological Sciences.* **366**, pp.119-120.

Al-Zubari, Al-Turbak, Abdulaziz, Zahid, Walid, Al-Ruwis, Khalid, Al-Tkhais, Ali, Al-Muataz, Ibrahim, Abdelwahab, Ahmed, Murad, Ahmed, Al-Harbi, Meshari and Al-Sulaymani, Zaher. 2017. An overview of the GCC Unified Water Strategy (2016-2035). *Desalination and Water Treatment.* **81**, pp.1-18.

Al Hashemi, Rahma, Zarreen, S, Al Raisi, A, Al Marzooqi, FA and Hasan, SW. 2014. A review of desalination trends in the Gulf Cooperation Council countries. *International Interdisciplinary Journal of Scientific Research.* **1**(2), pp.72-96.

Alazmi, Hamad J, Mitchell, Gordon and Trigg, Mark A. 2024. Kuwait household water demand in 2050: Spatial microsimulation and impact appraisal. *Water and Environment Journal.* **38**(1), pp.139-152.

Alazmi, Hamad J. 2022. *Investigating Water Conservation Strategies in Kuwait: A Micro- Component Backcasting Approach*. PhD thesis, University of Leeds.

Aleisa, Esra and Al-Zubari, Waleed. 2017. Wastewater reuse in the countries of the Gulf Cooperation Council (GCC): the lost opportunity. *Environmental monitoring and assessment.* **189**(11), p553.

Aliewi, A. and Alayyadhi, N. 2018. *Assessment of the daily per capita end use water consumption at residential areas in Kuwait using household surveys and real time ultra-sonic flow monitoring technology.* Kuwait: KISR.

Aliewi, Amjad, El-Sayed, Essam, Akbar, Adnan, Hadi, Khaled and Al-Rashed, Muhammad. 2017. Evaluation of desalination and other strategic management options using multi-criteria decision analysis in Kuwait. *Desalination.* **413**, pp.40-51.

Baalousha, H. and Ouda, O. 2017. Domestic water demand challenges in Qatar. *Arabian Journal of Geosciences.* **10**(24), p537.

Brooks, D., Brandes, O. and Urman, S. 2009. *Making the most of the water we have: The soft path approach to water management.* Earthscan.

Browne, A. L. 2015. Insights from the everyday: Implications of reframing the governance of water supply and demand from 'people'to 'practice'. *Wiley Interdisciplinary Reviews: Water.* **2**(4), pp.415-424.

Burney, A., Alawadhi, A., Gelan, A., Al-Fulaij, S., Al-Musallam, N., Awadh, W., Al-Khayat, A. and Al-Musallam, M. 2017. *Households' Conservation Behavior: A Case of Electricity and Water Demand in Kuwait.* Kuwait: KISR.

CBK. 2020. *Economic report 2020.* Kuwait: Central Bank of Kuwait.

CNBC. 2021. More than 400,000 expatriates have left Kuwait without return since 2020. *CNBC*. 1 July 2021.

Dabour, Nabil. 2006. Water resources and their use in agriculture in arab countries. *Journal of Economic Cooperation among Islamic Countries.* **27**(1).

de Waal, Dominick, Khemani, Stuti, Barone, Andrea and Borgomeo, Edoardo. 2023. *The Economics of Water Scarcity in the Middle East and North Africa: Institutional Solutions.* World Bank Publications.

Dreborg, Karl H. 1996. Essence of backcasting. *Futures.* **28**(9), pp.813-828.

Fadlelmawla, A. 2009. Towards sustainable water policy in Kuwait: Reforms of the current practices and the required investments, institutional and legislative measures. *Water resources management.* **23**(10), pp.1969-1987.

Flavin, Christopher. 2008. *State of the world 2008: Innovations for a sustainable economy*. Washington: Worldwatch Institute.

Gleick, Peter H and Cooley, Heather. 2021. Freshwater scarcity. *Annual Review of Environment and Resources.* **46**(1), pp.319-348.

Hamoda, Mohamed F. 2001. Desalination and water resource management in Kuwait. *Desalination.* **138**(1-3), pp.385-393.

Herrington, P. and Britain, G. 1996. *Climate change and the demand for water.* HM Stationery Office.

Ismail, H. 2015. Kuwait: Food and water security. *Strategic Analysis Paper, Future Directions International.*

Jern, N. G. 2006. *Industrial wastewater treatment.* World Scientific.

Jones, Edward, Qadir, Manzoor, van Vliet, Michelle TH, Smakhtin, Vladimir and Kang, Seong-mu. 2019. The state of desalination and brine production: A global outlook. *Science of the Total Environment.* **657**, pp.1343-1356.

doi:10.20944/preprints202603.2239.v1

Lattemann, S. and Höpner, T. 2008. Environmental impact and impact assessment of seawater desalination. *Desalination.* **220**(1-3), pp.1-15.

Liyanage, Shantha and Vishwanathan, Venkataraman. 2020. Diffusion of innovative water atomization technology to conserve water in water stress countries. *Journal of Applied Material Science & Engineering Research.* **4**(2).

Mabrok, Mohamed A, Saad, Ahmad, Ahmed, Taha and Alsayab, Hamad. 2022. Modeling and simulations of Water Network Distribution to Assess Water Quality: Kuwait as a case study. *Alexandria Engineering Journal.* **61**(12), pp.11859-11877.

McDonald, A. and Mitchell, G. 2013. Water demand planning and management. *Water Resources.* Routledge, pp.223-242.

MEW. 2022. *Water book.* Kuwait Ministry of Electricity and Water.

Mezher, T., Fath, H., Abbas, Z. and Khaled, A. 2011. Techno-economic assessment and environmental impacts of desalination technologies. *Desalination.* **266**(1-3), pp.263-273.

Moossa, Buzaina, Trivedi, Priyank, Saleem, Haleema and Zaidi, Syed Javaid. 2022. Desalination in the GCC countries-a review. *Journal of Cleaner Production.* **357**, p131717.

Mukhopadhy, A., Akber, A. and Al-Awadi, E. 2001. Analysis of freshwater consumption patterns in the private residences of Kuwait. *Urban Water Journal.* **3**(1-2).

Naseeb, Adel, Ramadan, Ashraf and Al-Salem, Sultan Majed. 2022. Economic feasibility study of a carbon capture and storage (CCS) integration project in an oil-driven economy: the case of the state of Kuwait. *International Journal of Environmental Research and Public Health.* **19**(11), p6490.

Odhiambo, G. 2016. Water scarcity in the Arabian Peninsula and socio-economic implications. *Applied Water Science.* **7**(5), pp.2479-2492.

OECD. 2021. *Greenhouse gas emissions.* Available from: https://www.oecd-ilibrary.org/energy/data/iea-co2-emissions-from-fuel-combustion-statistics_co2-data-en

PACI, the public authority for civil information. 2022. *Population by nationality.* Available from: http://stat.paci.gov.kw/englishreports/

Pahl-Wostl, Claudia. 2007. The implications of complexity for integrated resources management. *Environmental Modelling & Software.* **22**(5), pp.561-569.

Roccaro, P., Falciglia, P. and Vagliasindi, F. 2011. Effectiveness of water saving devices and educational programs in urban buildings. *Water Science and Technology.* **63**(7), p1357.

Rogers, Everett M. 2010. *Diffusion of innovations.* Simon and Schuster.

Rogers, Everett M. 2002. Diffusion of preventive innovations. *Addictive behaviors.* **27**(6), pp.989-993.

Salim, Abdalla Mahmoud and Alsyouf, Imad. 2020. Development of renewable energy in the GCC region: status and challenges. *International Journal of Energy Sector Management.*

Shaker, Hani. 2015. 400 million barrels of oil per annum for seawater desalination. *Al-Rai*. 27th of May 2015.

Siderius, C, Conway, D, Yassine, M, Murken, L and Lostis, PL. 2019. *Characterising the Water-Energy-Food Nexus in Kuwait and the Gulf Region (London: Middle East Centre, LSE).*

Stavenhagen, Martin, Buurman, Joost and Tortajada, Cecilia. 2018. Saving water in cities: Assessing policies for residential water demand management in four cities in Europe. *Cities.* **79**, pp.187-195.

Waliszewski, P and Konarski, J. 2005. A mystery of the Gompertz function. *Fractals in biology and medicine.* Springer, pp.277-286.

World Bank. 2017. *Beyond Scarcity: Water Security in the Middle East and North Africa.* The World Bank.