The Future of Water in the United Arab Emirates: Local and National Calls for Change

Aarushi Dahiya; Yiqian Liu

Monday 21st of August, 2023

Abstract

Water scarcity is an increasingly significant issue for the United Arab Emirates. The country's diminishing groundwater reserves, rising per capita demand, and reliance upon energy-intensive desalination threaten future water security. This report explores the problem in a local and national context, analyzing irrigation patterns in the case study of Jumeirah English Speaking School and broader country-level usage over time. Statistical modeling helped reveal seasonal fluctuations and generate relevant forecasts. National water usage is projected to reach 2.22 billion m^3 in 2030 and 2.64 billion m^3 in 2040. The corresponding increase in demand will have severe environmental implications: a 0.8 billion kg increase in annual CO_2 emissions by 2030 if current desalination technology remains unchanged. Upon such enhanced understanding of the implications of freshwater production, we devised a set of national- and local- level targets. Recommendations include improving desalination practices, recycling wastewater, and behavioral science-based public campaigns; locally, we suggested changes to plumbing and irrigation methods and a community reporting system to minimize water wastage.

Contents

Introduction

1.1 Background

The issue of water scarcity holds massive consequences for the United Arab Emirates' policy and development. The country's groundwater reserves are among the lowest in the world and rapidly diminishing; its dependence on desalination is responsible for immense and growing quantities of greenhouse gas emissions. Paradoxically, the country's water consumption per capita ranks among the highest in the world (ITA, 2019). There is an immense difference between what the UAE desert can reasonably support and what its residents demand, and this difference has created a growing crisis in water management that will affect generations to come. As high school students, we are deeply concerned about current practices and the future of water security in the Emirates.

The purpose of this report is to explore the extent of the issue by contextualizing abstract statistics via data analysis and hence formulate recommended improvements. We chose to examine the overarching problem first through our school's usage patterns, designing realistic targets at a local level. We then take a broader national view, suggesting policy and corporation-level changes that are necessary to ensure a future where water remains sustainably accessible to all.

1.2 Methodology

To gain a more conceptual understanding of water scarcity in the UAE and the environmental implications of water production, various data is collected and analyzed to generate contextualized conclusions. Jumeirah English Speaking School (JESS) is investigated due to its contextual proximity and personal relevance; national analysis helps render a holistic picture of water usage like the emissions from desalination (the main source of UAE's freshwater).

In addition to better understanding water scarcity, various relevant strategies and techniques are evaluated and recommended as solutions to ameliorate the environmental impact of water production.

1.2.1 Our School

Jumeirah English Speaking School, (Arabian Ranches campus) is a coeducational school with over 2050 students (Which School Advisor, 2023) and a campus area of approximately 34,830 m^2.[1] The school is located in Arabian Ranches, a residential area in Dubai, United Arab Emirates.

1.2.2 Data Collection

National data are sourced either from governmental reports or international agencies. JESS irrigation data are historical recordings of a water meter.

2 Jumeirah English Speaking School

2.1 Data Analysis

JESS records school-wide irrigation water usage weekly. This data has a saved history since January 2022. Every Sunday, the reading from a cumulative water meter is recorded. The dataset has some gaps during certain school holidays.

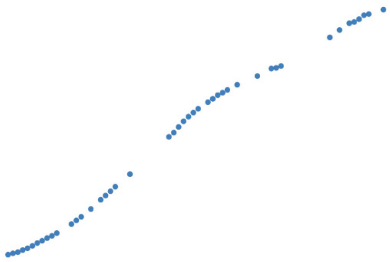

Figure 1: Water meter raw readings

Figure 2: Weekly delta of readings

Figure 1 is a crude scatter of the datapoints; the horizontal axis represents time while the vertical axis is a scale of the raw readings. This cumulative graph demonstrates interesting curvatures prompting further investigation.

A plot of the weekly change of water used (Figure 2) demonstrates a sinusoidal shape. The shape and periodicity of the pattern suggests a seasonality effect caused by the natural yearly weather cycle – plants require more water during the summer to compensate for higher temperatures and evaporation rates.

There are visible irregularities in the more recent part of the dataset (weeks 70 to 80) – the usage is lower than what previous patterns may indicate. This might be explained by the recent replantation of the grass field, which called for a pause in that area's irrigation. This event introduced this visible one-time anomaly in the data. Otherwise, the data demonstrates an average rate of increase of around **620 m^3 per week**.

The above statistics – both the cumulative and instantaneous (discrete) figures – are presented on Figure 3:

[1] Estimated using satellite data via Google Maps.

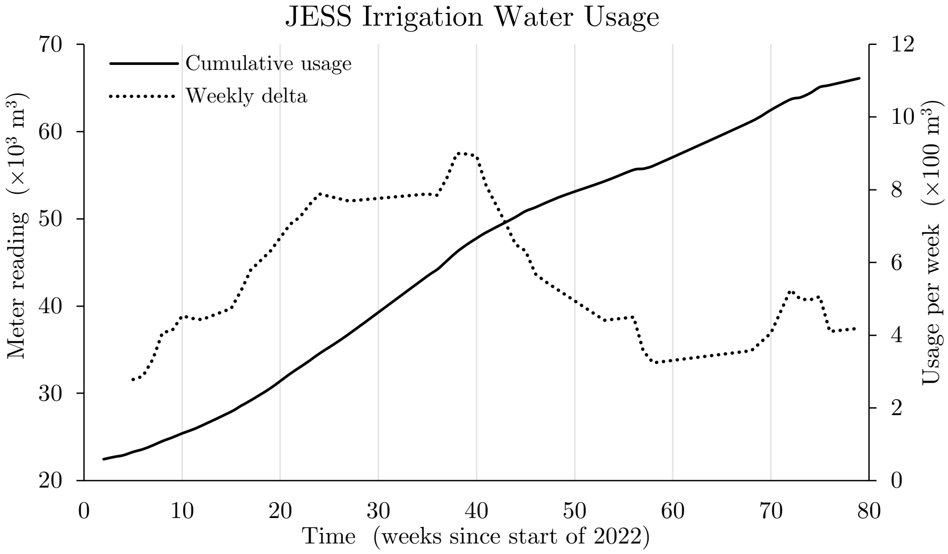

Figure 3: Graph of JESS irrigation water usage

2.1.1 Extrapolation

Catering for the data's nature as a time series and its seasonal characteristics, forecasting software Prophet (Taylor & Letham, 2017) was used to draw predictions of and quantify patterns in the water usage.

The data can be described by two features: a linearly increasing trend and periodic seasonal fluctuations. The periodic variations were modelled well by a Fourier series of order one, which is basically a sinusoidal function. The modelled predictive pattern is visualized in Figure 4.

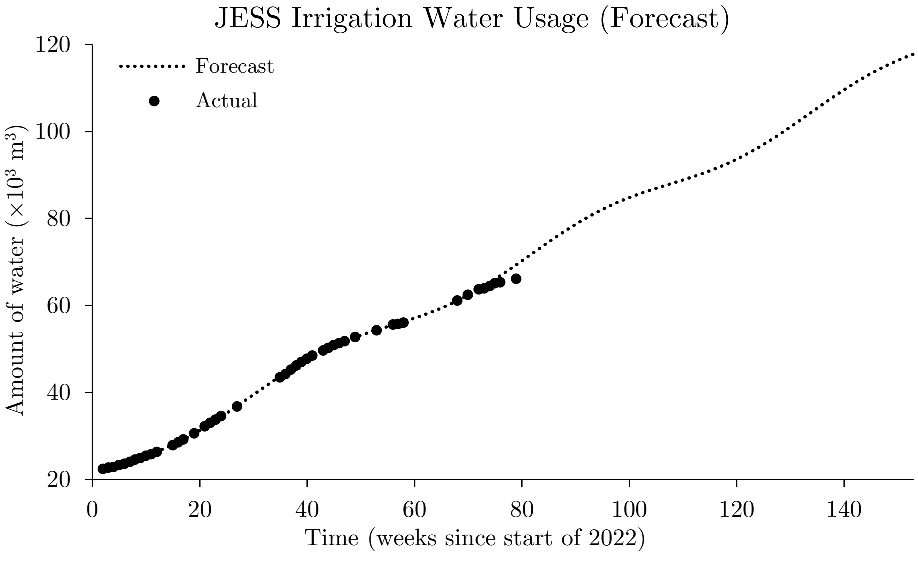

Figure 4: Graph presenting a forecast of JESS irrigation water usage

These observations composed the forecast of future water meter readings. The predictor calculated a linear increase of **625 m^3 per week** (very similar to the average found above). The seasonal effects follow an additive sine pattern with an amplitude of 2055 m^3 centered on the 19th of July. In other words, the cumulative usage can be approximated by:

$$W_c(x) = 625x + 2055\, sin\left(\frac{x - 29.3}{8.30}\right) + C \tag{1}$$

where $\mathrm{W_c}$ is the cumulative reading, x is the number of weeks since the start of a year, and C is an arbitrary constant accounting for any previous cumulation.

This function's derivate, or the model of the weekly usage, makes more intuitive sense; at an average usage of 625 m^3 per week as discussed above, the seasonal effects have an amplitude of 247 m^3 and its **peak** is located on the 19th of July. These figures have more direct meaning. For example, the range of the function indicates the difference between the highest and lowest usage per week to be around **495 m^3**; a **ratio of 2.3**. (In the actual data, due to outliers and the lack of smoothing, the maximum difference is over 600 m^3.) The function, $\mathrm{W_r}(x)$, is as follows:

$$W_r(x) = 247\, cos\left(\frac{x - 29.3}{8.30}\right) + 625 \tag{2}$$

2.1.2 Takeaways

Select desert plants:

From the seasonality analysis, summertime is observed to consume up to 2.3 times the amount of water used in winter. This raises questions about the choice of plants and their water requirements; desert plants adapted to hot climates may considerably reduce water consumption from irrigation.

Minimize vegetation:

Plainly, maintaining greenery in a desert climate is a massive water sink. The lack of rainfall means almost all the plants' water requirements must be artificially supplied. Worse still, high temperatures, low humidity, and sandy soil accelerate transpiration and increase evaporation and runoff losses, further increasing water consumption. In numbers, it is seen that JESS spends 620 m^3 per week to maintain approximately 9,330 m^2 [2] of grass field and 400 m^2 [3] of general vegetation. This equates to 2.5 inches (6.27 cm) of water (per area) per week. In perspective, this weekly

[2] As measured using Google Maps with satellite images.
[3] An estimation similar to 2

consumption is worth 3.5 years of one person's domestic use.[4] Indeed, UAE's desert climate contributes significantly to these figures – similar fields in subtropical regions only require 1 inch per week (Lawrence, 2022).

With the lack of abundant sources of freshwater, it is advisable to reduce real vegetation wherever possible. Substitutes like artificial grass for fields will very noticeably reduce water consumption.

2.2 Broader Relevance

While this case study seems limited in scope and high in specificity, a few universal observations were outlined in 2.1.2 Takeaways. In addition, there are many other private institutions of similar size and layout, making this investigation representative of at least a typical school. Regardless, the scale of water consumed by turf grass has been exposed.

3 Generalization

3.1 National Water Use

The following investigation uses two metrics of water use: consumption and withdrawal. Withdrawal is the gross amount of water extracted from natural sources (including production via desalination). Consumption is the net withdrawn amount that is *not* returned to its source.

For the UAE, withdrawal statistics were sourced from the United Nations Food and Agriculture Organization AQUASTAT database, while the Bayanat portal of the UAE government provided water "usage" datasets. This said water usage is understood to be the total measured municipal water supplied throughout the country. Hence, while it is neither consumption by formal definitions nor withdrawal, this figure is relevant as it reflects the demand of domestic-grade freshwater. (And this water "usage" will be hereafter referred to as consumption.) This data is rendered in Figure 3.

Withdrawal appears to be roughly 3.1 times that of consumption. Consumption and withdrawal increase at averages of 42.2 and 71.8 million m^3 per year, respectively. During **2023**, the UAE would consume **1.92 billion m^3** of water.[5]

[4] Comparing to Usage per Capita calculated in 3.1 National Water Use
[5] As projected (linear trend)

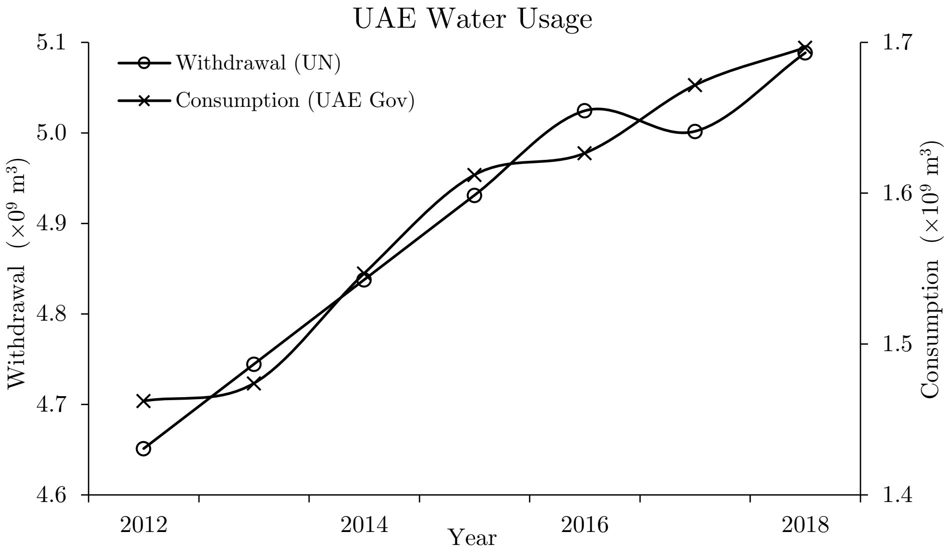

Figure 5: Graph of UAE's yearly water withdrawal and consumption over time

Consumption per capita

National water use is considered alongside population data to investigate any trends in consumption per capita. Two sources of population data are considered: UN estimates and governmental estimates. These two sources disagree with a non-negligible difference (Figure 6), so they are presented in parallel for comparison wherever appropriate.

It is evident that the UN's data resembles a superficial model due to its linearity. In general, the UN's estimates are lower than the governmental estimates. Projections of both datasets are made using a linear function that follows latest trend of the dataset (which is correspondingly linear, as seen in Figure 6). The UN and governmental numbers increase at averages of 80 and 125 thousand people per year, respectively. These projections are used later in some of the national water consumption forecasts.

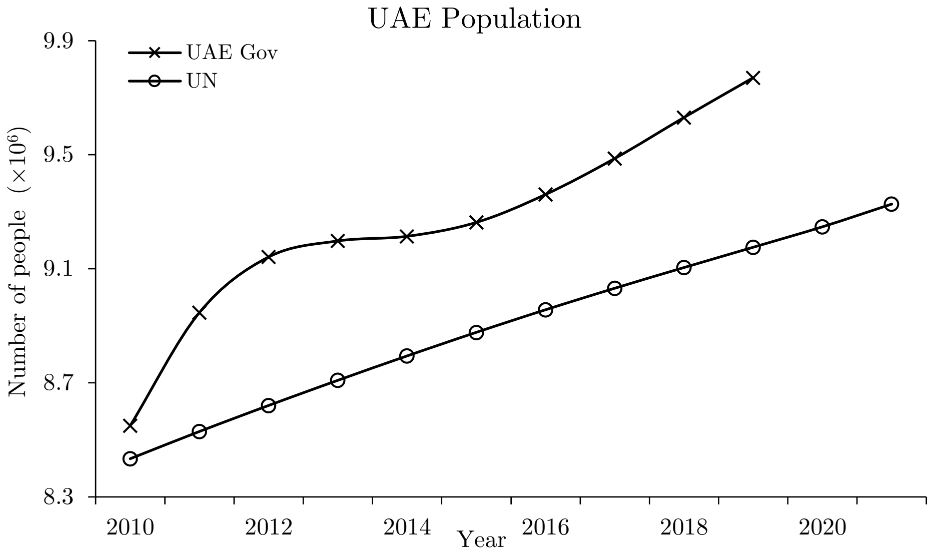

Figure 6: Graph of UAE's population estimates over time

The consumption per capita (Figure 7) is projected using a decreasing power function increasing between 1.6 and 0.6 m^3 per year. A linear projection is not used here as no evidence or logic suggests that each person would use water at a consistently faster rate as time passes; the (although limited) data does not demonstrate strong linearity. It is more reasonable that the current upwards trend will gradually plateau.

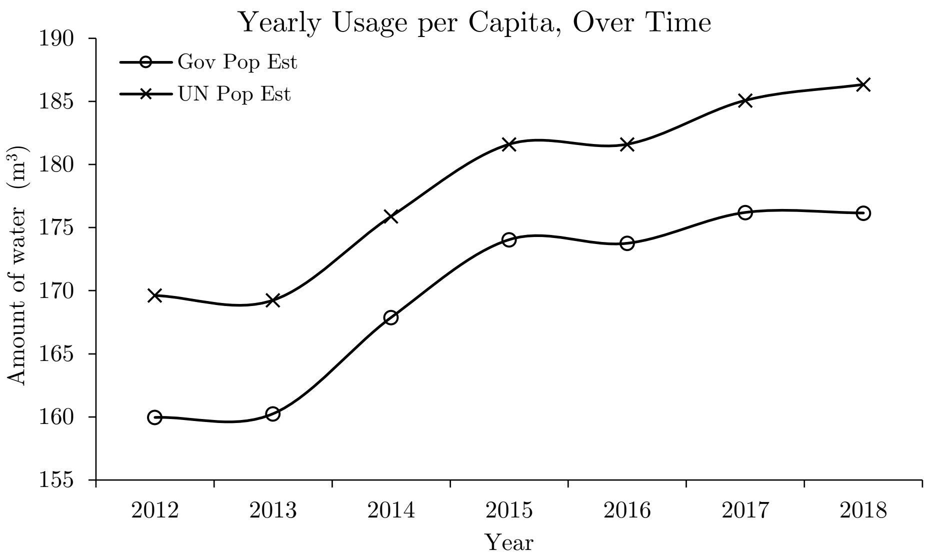

Figure 7: Graph demonstrating an increase of yearly per-person water usage over time

3.1.1 Predictions

Predictions of the national water consumption are projected using two different methods yielding three different results, as presented in Figure 8.

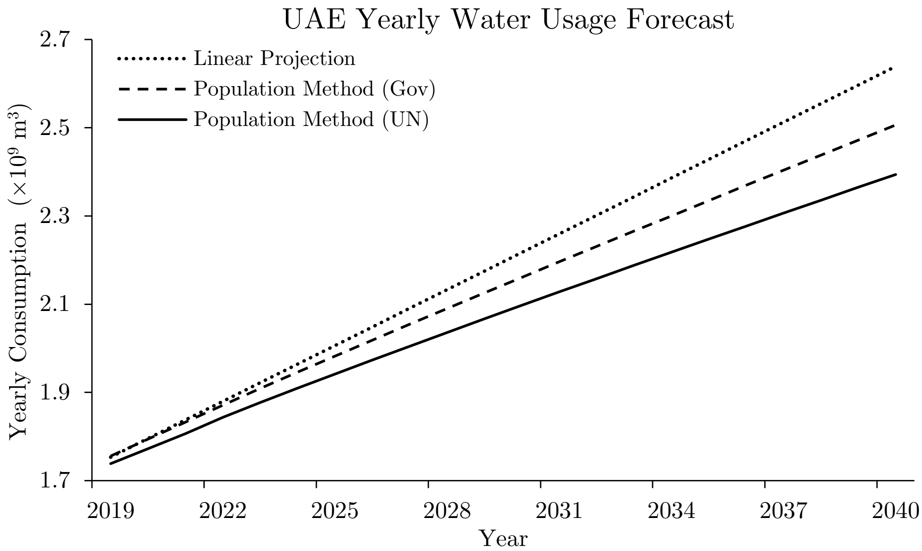

Figure 8: Graph of different forecasts of UAE's future yearly water consumption

The most basic method is a linear extension of the trend in Figure 5. This yields the highest values: 2.22 billion m^3 in 2030 and 2.64 billion m^3 in 2040.

"Population Method" is a factor-based approach where the product of population and usage-per-capita predictions are taken as an indirect result. Because the usage per person is not expected to be very volatile, this method depends more on the population predictions, which is commonly estimated by agencies and governments alike. Anchoring the water consumption predictions on a more "common" statistic like population might increase its accuracy and allows for naturally non-linear models.

There are two sets of predictions via this method, using each of the two projections of population based on current data from either the UN or the government. The different predictions at key timepoints are summarized in Table 1. (PM is Population Method; units in billions of m^3.)

Year	**Linear**	**PM** (Gov)	**PM** (UN)
2030	2.22	2.16	2.10
2040	2.64	2.51	2.39

Table 1: Tabular comparison of different forecast results

For exact values at specific years, see the table in 7.2 All Data.

3.2 Environmental Implications

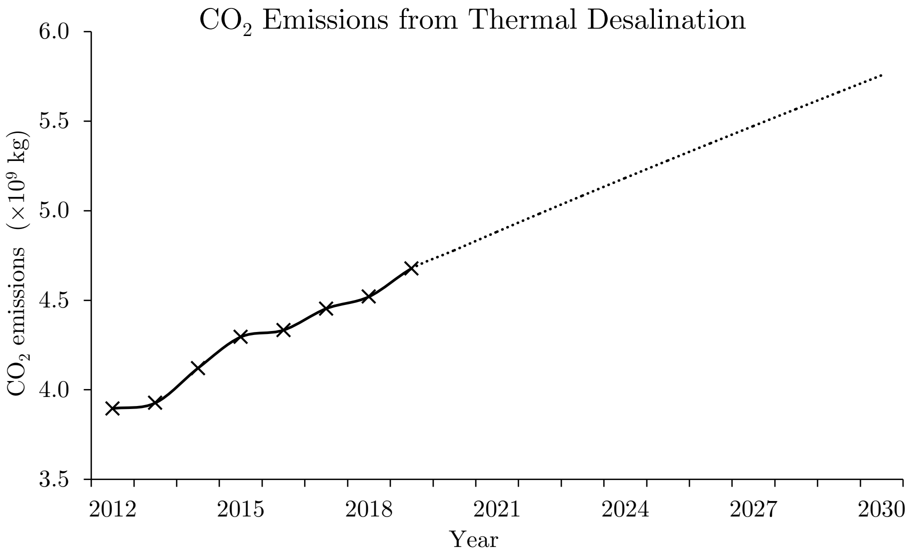

Figure 9: Graph illustrating approximate CO_2 emissions from thermal desalination, derived from water consumption measured values (2012–18) and predictions (2019–30)

As the UAE population rises – and with it the per capita demand for water – the country's reliance upon desalination will continue to grow. Desalination is a highly energy-intensive process, especially the thermal methods that are generally used in the UAE. As the exact composition of different methods is not known, we estimate that, on average, desalination in the UAE necessitates 16 kWh of energy per m^3 of water (see Table 2). This energy is mostly generated from natural gas (Walton, 2019), which releases 0.185 kg of CO_2 per kWh (Carbon Independent, 2023). This translates to about 5 billion kg of CO_2 emitted per year in 2023 and 5.8 billion in 2030. This increase in annual emissions is the rough equivalent of having **an additional 174,000 cars** on the road.[6]

In cumulative terms, in the seven years from 2023–30, thermal desalination in the UAE will have released approximately 3.8×10^9 kg of CO_2 into the atmosphere. For context, the average UAE resident would take over 174,000 years to emit this amount.[7] 174,000 years ago, early humans had essentially just begun to develop language (Pagel, 2017).

From this perspective, it becomes obvious that using thermal desalination in the medium to long term would be catastrophically unsustainable.

[6] Assuming the average passenger car releases 4600 kg of CO_2 p.a. (US EPA, 2023)
[7] Based on the 2021 per capita emissions of 21.79 metric tonnes (Ritchie, Roser, & Rosado, 2020)

Switching to less environmentally destructive methods of obtaining water is imperative and should be considered a matter of urgency. These alternatives are explored and evaluated in further detail in 4 The Future of Water.

3.3 Evaluation

Weaknesses of the above analysis mainly reside in the sources of data. Both water usage and population data exhibited low corroboration between different sources, such as the government and the UN (for population). The lack of agreement both produces differing results and lowers the reliability of said data. However, this is well beyond the control of such investigations. Ultimately, the most important takeaway are the methods presented and **the general direction** of conclusions drawn. Specifically, the variance in population data causes disparities in water usage predictions of up to 10% in 2040 and diverges to 14% in 2050.

Otherwise, linearity in most of the projections may be an oversimplification, as complex systems tend to exhibit nonlinearity, but there is no justification to use any other (more complex) models.

The Population Method aims to reduce the inaccuracies in the forecast by limiting the model's uncertainty to a single point – the prediction of population growth. As explained earlier, there are often credible sources of population estimates from professional agencies, which indirectly provides higher accuracy than directly regressing raw data.

4 The Future of Water

The bigger picture: national context

The United Arab Emirates has an arid desert climate, limiting groundwater availability for consumption and industrial usage. Indeed, while groundwater has historically been used for these purposes, a 2015 study found that UAE groundwater levels are steadily declining at an approximate rate of 0.5 centimeters per annum (Sanchez, Ouarda, Marpu, & Allam, 2016). Coupled with the Emirates' rapidly growing population, this depletion renders existing water use practices unsustainable beyond the next few decades.

Thermal desalination therefore accounts for the largest proportion (over 90%) of potable water (Meshkati, 2019). The country uses several different desalination technologies, chiefly multiple-effect distillation (MED) and multiple-stage flash distillation (MSF), with small amounts of reverse osmosis (RO) (UAE Government Portal, 2023). Although these methods for water distillation have been effective in the short term, they are not sustainable long-term strategies as they require excessive amounts of input energy. Theoretically, the average desalination energy requirement is 0.86 kWh m^{-3} (DESWARE, 2023). However, inefficiencies cause the actual figure to be far higher, as summarized for these three technologies in the table below.

Process	**Total energy consumption (kWh m^{-3})**	**Ratio of actual to theoretical energy consumption**
RO	3 – 3.5	3.5 – 4 ×
MED	6.5 – 11	7.5 – 13 ×
MSF	13.5 – 25.5	16 – 30 ×

Table 2: A comparison of energy consumption by desalination method (DESWARE, 2023)

As conveyed in Table 2, the actual energy consumption per cubic meter of the three most used desalination techniques can be many times higher than the theoretical value. At present, most of this energy is supplied by conventional fossil fuel combustion. Given the non-renewable nature of these fuels, coupled with their harmful implications for the climate and global systems, a new approach is clearly needed.

4.1 Targeted Recommendations

Improving desalination

An important step is to improve renewable infrastructure, enabling sustainable sources of energy to be used for desalination. The UAE has already made forays into solar desalination, with the Dubai Electricity and Water Authority (DEWA) planning the construction of the world's first solar desalination plant in Jebel Ali (Cabral, 2022). However, it is imperative that renewable desalination is considered less a novelty, more a necessity. Government and private investment will be crucial to refining this technology, enabling it to be used more widely in the UAE. A further consideration is retrofitting; given that UAE production accounts for 14% of the world's desalinated water (UAE Government Portal, 2023), it is important to adapt existing infrastructure to be environmentally sustainable. Where possible, this should be done by incorporating renewables. Until then, we should focus our efforts on improving efficiencies, thus reducing the energy-intensity of conventional processes.

Wastewater recycling

An alternative approach is to circumvent desalination altogether, or at least reduce its demand. Various countries have successfully implemented wastewater purification systems. These systems allow water to be recycled efficiently, significantly reducing overall wastage – a key consideration given the UAE's diminishing groundwater supply. A notable example is Singapore's NEWater Project, which processes treated wastewater into high-grade reclaimed water, suitable for human consumption (Singapore Public Utility Board, 2022). This system successfully "meets nearly 40% of the country's water demand" (Yao, et al., 2020), with a relatively low energy input of 0.6–0.8 kWh m^{-3}. While the UAE does carry out some wastewater recycling, this is primarily for 'grey water' uses, such as irrigation. Improving the grade of this recycled water could make it suitable for 'white water' uses, such as drinking and domestic supply. Singapore, too, contended with water scarcity: it has no natural aquifers or groundwater (Khoo, 2009). NEWater proved to be highly effective under these conditions, making it a potentially viable strategy for the UAE. Grey water supply systems could themselves stand to be improved; there is no direct provision to households, offices, and schools, meaning that desalinated white water is typically used for irrigation. Making recycled grey water cheaply accessible for this use would greatly reduce public demand for white water.

Awareness campaigns do not suffice

It is also vital to consider the behavioral aspects of climate messaging. Generic messaging (posters, awareness drives etc.) tend to be a less effective form of intervention. This is because individual consumers are unlikely to see themselves as directly responsible for a larger issue, especially if they have no metric for comparing their own impact against that of others.

Regardless, this conventional form of messaging is widely used by many environmental campaigns; Figure 10 is an example of a "generic" message encouraging people to save water, by the Dubai Electricity and Water Authority (DEWA):

Figure 10: Image from a 2015 awareness program run by DEWA.

Behavioral interventions

While these campaigns may have some amount of success in raising awareness, we argue that they have little utility in today's world. A 2013 study found that "over 84% of nationals admit water is wasted in the UAE" (Emirates Center for Strategic Studies and Research, 2013). This figure reflects attitudes over a decade ago, and environmental awareness has only grown since. Given this context, it becomes immediately clear that UAE residents are already aware of the need to save water. Therefore, the driving factor in wastage is not a poorly informed population. This renders informational campaigns largely obsolete in addressing the issue.

The issue demands a more nuanced approach, rooted in principles of behavioral science. The main weakness of existing campaigns is that they are far too generic; they tell the individual nothing about how much water they are using relative to others, or how exactly they can reduce wastage. There is little understanding or incentive to change one's behavior.

Inspiration for an alternative comes from an unlikely place: a UK study on reducing the overprescription of antibiotics. The highest-prescribing GPs were sent personalized letters from the Chief Medical Officer, explaining that their prescription rates were in the top 20% for their area (Hallsworth, et al., 2016). These letters accomplished several important aims:

(i) Many of these GPs were unaware that their prescription rates were relatively high. Including a clear statistic, comparing their rates to averages of the local area, led to increased awareness in the individuals who contributed the most to a larger issue.

(ii) The inclusion of the statistics exerted a subtle social pressure. Being identified as 'worse than the norm' pushed these GPs to change their prescription practices, as people are generally averse to being perceived in this way.

(iii) The letters also listed a set of specific alternatives to prescribing antibiotics. Knowing these better options made it easier to shift away from the harmful practice.

The campaign was relatively low-cost and proved to be highly effective, producing a statistically significant decrease in antibiotic prescription rates. The key insight offered by this study is that social comparison is a highly effective tactic in changing behaviors.

This powerful idea should inform water-saving campaigns in the 2020s. Similar to the medical study, a DEWA-issued communication to the highest 20% of water-intensive households, schools, and businesses, informing these groups of their percentile and suggesting ways to cut down, promises to be successful. Furthermore, this sort of percentile ranking could be prominently displayed at the top of water and energy bills, comparing consumers to others in their local area and providing actionable recommendations for improvement.

In addition, we recommend a competitive element: government-administered national ‘league tables’ for schools, publicly ranking them according to water usage, with recognition for the best-performing schools. The schools at the bottom would be incentivized to improve; those at the top, to out-compete each other. Being able to see one’s school rising through the rankings would foster a sense of concrete achievement for an otherwise largely intangible set of actions. Competition has had proven success in climate behavioral studies, pushing subjects to decrease their energy consumption (Kelleher, 2016). While there is no “silver bullet” to saving water, very much relies upon human beings changing their habits; applying behavioral findings is crucial to that change.

Summary of national-level priorities

(i) The accessible provision of recycled ‘grey water’ for domestic and commercial use, at lower pricing than desalinated ‘white water’.

(ii) The adoption of wastewater recycling as a viable alternative to thermal desalination, and the introduction of this water into the water supply.

(iii) Increased funding and attention to renewable desalination methods, particularly solar-powered plants.

(iv) Implementing targeted behavioral campaigns, enabling quantifiable social comparison, and focusing on those who are the most wasteful. Adopting competition-based systems for encouraging water saving.

School and community-based interventions

While larger-scale actions are paramount and would have the largest impact, it is also possible for schools and local communities to enact change. Much of this would follow from national interventions, such as starting to use grey water or competing for water efficiency. Until this is possible, we specifically recommend the following:

(i) **Installing water-efficient tap aerators in bathroom sinks:** Aerators can be cheaply added on to existing taps and can reduce water usage by 8–18% in daily use (Vaverka, Jakimiuk, Trach, Koda, & Vaverková, 2021).

(ii) **Adjusting irrigation times to early morning or late evening, especially in summer:** Doing so would minimize water loss from evaporation and improve outcomes for plant health (US EPA, 2022)

(iii) **Review current irrigation practices:** In the JESS case study, field irrigation is carried out through a pre-programmed system, with water levels varying on a seasonal basis. It is possible, indeed likely, that this system contains flaws: for example, unnecessarily deep watering or a non-optimized watering frequency. We recommend that the underlying algorithm be reviewed to identify and correct these flaws. Eliminating inefficiencies could reduce water wastage in the long run.

(iv) **Create a community reporting app for sprinkler leaks:** In the housing community Arabian Ranches, communal greenery is irrigated through a sprinkler system managed by Emaar. We have anecdotally found sprinkler or pipe leaks in this system to be relatively common. Although these leaks are quickly observed by residents walking outside, it generally takes longer for the authority to be informed and organize a repair. In the meantime, large quantities of water are wasted at high pressure. To reduce this wastage, we recommend the creation of a mobile app for residents to report communal water leaks based on location. We believe that this would reduce the response time for repairs, saving both water and cost. Although this recommendation is based on firsthand experience of Arabian Ranches, it is likely applicable to other communities in the area with shared irrigation systems.

N.B. These recommendations have been developed specifically for the authors' school and community but can (and should) be extended to office buildings, shopping malls and other residential and school areas. Their fundamental objective is to save water in Dubai's arid setting, and for this reason the underlying principles are strongly applicable beyond the immediate area.

5 Conclusion

Water scarcity in the UAE could be reasonably described as a hidden crisis. The region is in perpetual drought with limited groundwater reserves. Rising standards of living have placed inordinate pressure on these resources, and supplying this demand is only possible through environmentally destructive desalination. This rise in demand shows no sign of slowing; our analysis presents a bleak view of a world where the status quo continues unchecked. Irrigation for non-agricultural vegetation is a massive sink of water with a strong seasonal fluctuation that imposes further stresses on desalination infrastructure in the summer. This calls for an evaluation of the necessity of decorative plants, further stressing the importance of species selection to minimize water requirements.

The issue of water security is a complex one for policymakers and individuals alike, but the major sources of crisis can be distilled down and tackled through specific interventions. We have outlined several important approaches to make UAE lifestyles compatible with environmental limitations. We call for these interventions, small and large, to be implemented as a matter of urgency. We have an ethical imperative to act, ensuring the future of water security in the Emirates and the wider world.

6 Works Cited

Bayanat Portal. (2020, October). Quantity of Used Water in United Arab Emirates. Retrieved July 30, 2023, from https://admin.bayanat.ae/File/Get?id=0cef7c07-b81f-4b04-a493-dbd2af90d10b

Bayanat Portal. (2020, April). UAE Total Population Estimates by Age Groups and Gender. Retrieved July 30, 2023, from https://admin.bayanat.ae/File/Get?id=0865e122-72d5-4e85-845e-a6874fee45be

Cabral, A. R. (2022, September 20). *Dewa and Dutch start-up Desolenator to build solar-powered desalination system*. Retrieved from The National: https://www.thenationalnews.com/business/road-to-net-zero/2022/09/20/dewa-and-dutch-start-up-desolenator-to-build-solar-powered-desalination-system/

Carbon Independent. (2023). *Emissions from home energy use*. Retrieved from Carbon Independent: https://www.carbonindependent.org/15.html

Department of Economic and Social Affairs - Population Division. (2022). World Population Prospects 2022. Retrieved July 30, 2023, from https://population.un.org/wpp/Download/Files/1_Indicators%20(Standard)/EXCEL_FILES/1_General/WPP2022_GEN_F01_DEMOGRAPHIC_INDICATORS_COMPACT_REV1.xlsx

DESWARE. (2023). *Energy Requirements Of Desalination Processes*. Retrieved from Encyclopedia of Desalination and Water Resources: https://www.desware.net/Energy-Requirements-Desalination-Processes.aspx

Dubai Electricity and Water Authority. (2015, August 15). *DEWA launches Every Drop Matters campaign*. Retrieved from Dubai Electricity and Water Authority: https://www.dewa.gov.ae/en/about-us/media-publications/latest-news/2015/08/dewa-launches-every-drop-matters-campaign

Emirates Center for Strategic Studies and Research. (2013, April 1). *Over 84% of Nationals Admit Water is Wasted in the UAE, Says Study*. Retrieved from Emirates Center for Strategic Studies and Research: https://www.ecssr.ae/en/over-84-of-nationals-admit-water-is-wasted-in-the-uae-says-study/

Food and Agriculture Organization of the United Nations. (2023, March 15). FAO AQUASTAT Dissemination System. Retrieved July 30, 2023, from https://data.apps.fao.org/aquastat/

Hallsworth, M., Chadborn, T., Sallis, A., Sanders, M., Berry, D., Greaves, F., . . . Davies, S. C. (2016). Provision of social norm feedback to high prescribers of. *The Lancet*.

ITA. (2019). *United Arab Emirates - Water*. Retrieved from International Trade Administration: https://www.export.gov/apex/article2?id=United-Arab-Emirates-Water

Kelleher, K. (2016). *Changing Habits, Saving Power*. Retrieved from UCLA Blueprint: https://blueprint.ucla.edu/feature/changing-habits-saving-power/

Khoo, T. C. (2009). *Water Management in 2020 and Beyond*. Berlin, Heidelberg: Springer.

Lawrence, C. (2022, October 10). *Here's how much you should water your lawn to keep it green according to the experts*. Retrieved August 1, 2023, from Tom's Guide: https://www.tomsguide.com/how-to/how-much-should-you-water-your-lawn

Meshkati. (2019, June 26). *Gulf Escalation Threatens Drinking Water*. Retrieved from Harvard Kennedy School Belfer Center for Science and International Affairs: https://www.belfercenter.org/publication/gulf-escalation-threatens-drinking-water

Pagel, M. (2017, July 24). *Q&A: What is human language, when did it evolve and why should we care?* Retrieved from BMC Biology: https://bmcbiol.biomedcentral.com/articles/10.1186/s12915-017-0405-3

Ritchie, H., Roser, M., & Rosado, P. (2020). *United Arab Emirates: CO2 Country Profile*. Retrieved from Our World in Data: https://ourworldindata.org/co2/country/united-arab-emirates

Sanchez, R. G., Ouarda, T. B., Marpu, P. R., & Allam, M. (2016). Water Budget Analysis in Arid Regions, Application to the United Arab Emirates. *Water*. Retrieved from https://www.ku.ac.ae/uae-groundwater-levels-falling-by-5cm-per-year-according-to-new-masdar-institute-research

Singapore Public Utility Board. (2022). *NEWater*. Retrieved from Public Utility Board: https://www.pub.gov.sg/watersupply/fournationaltaps/newater

Taylor, S. J., & Letham, B. (2017, September 27). Forecasting at Scale. *PeerJ Preprints*. doi:10.7287/peerj.preprints.3190v2

UAE Government Portal. (2023, May 09). *Water Security Strategy 2036*. Retrieved from UAE Government Portal: https://u.ae/en/information-and-services/environment-and-energy/water-and-energy/water-

US EPA. (2022, September 8). *When it's Hot*. Retrieved from United States Environmental Protection Agency: https://www.epa.gov/watersense/when-its-hot

US EPA. (2023). *Tailpipe Greenhouse Gas Emissions from a Typical Passenger Vehicle*. Retrieved from United States Environmental Protection Agency: https://www.epa.gov/greenvehicles/tailpipe-greenhouse-gas-emissions-typical-passenger-vehicle

Vaverka, I., Jakimiuk, A., Trach, Y., Koda, E., & Vaverková, M. (2021). Consumption and Savings of Drinking Water in Selected Objects. *Journal of Ecological Engineering*, 13-25.

Walton. (2019, January 21). *Desalinated water affects the energy equation in the Middle East*. Retrieved from International Energy Agency: https://www.iea.org/commentaries/desalinated-water-affects-the-energy-equation-in-the-middle-east

Which School Advisor. (2023). *Jumeirah English Speaking School Review*. Retrieved from Which School Advisor: https://whichschooladvisor.com/uae/school-review/jumeirah-english-speaking-school

Yao, B., Feng, S., Yaoyao, Z., Junyi, X., Yunsheng, W., Xuegeng, L., . . . Baolin, Z. (2020). Long-term performance and economic evaluation of full-scale MF and RO process – A case study of the changi NEWater Project Phase 2 in Singapore. *Water Cycle*, 128-135.

7 Appendix

7.1 Raw Data

7.1.1 JESS Irrigation

Week # is the number of weeks since the start of 2022. There are holes in the data. Figures are in cubic meters (m^3), rounded to the nearest integer.

Week	Cumulative Reading	Weekly Change	Week	Cumulative Reading	Weekly Change	Week	Cumulative Reading	Weekly Change
2	22 450	–	*21*	32 237	824	*46*	51 306	428
3	22 699	249	*22*	32 989	752	*47*	51 809	503
4	22 903	204	*23*	33 755	766	*49*	52 722	457
5	23 284	381	*24*	34 566	811	*53*	54 281	376
6	23 597	313	*27*	36 804	746	*56*	55 607	464
7	24 032	435	*35*	43 441	830	*57*	55 737	130
8	24 529	497	*36*	44 192	751	*58*	56 063	326
9	24 940	411	*37*	45 203	1 011	*68*	61 157	509
10	25 411	471	*38*	46 210	1 007	*70*	62 474	659
11	25 816	405	*39*	47 035	825	*72*	63 679	603
12	26 299	483	*40*	47 765	730	*73*	63 906	227
15	27 900	534	*41*	48 449	684	*74*	64 406	500
16	28 570	670	*43*	49 618	585	*75*	65 101	695
17	29 198	628	*44*	50 218	600	*76*	65 320	219
19	30 589	696	*45*	50 878	660	*79*	66 102	261

Table 3: Raw data from irrigation water meter at JESS

7.1.2 UAE Population Estimates

There were two major sources of population estimates for the UAE: official government datasets and the United Nations WPP Demographic statistics. Figures are in thousands of people, truncated to the nearest integer. (Table 4)

	Estimates Source	
Year	**Gov**	**UN**
2010	8 549	8 433
2011	8 946	8 529
2012	9 141	8 620
2013	9 197	8 709
2014	9 214	8 794
2015	9 262	8 877
2016	9 360	8 956
2017	9 487	9 032
2018	9 630	9 104
2019	9 770	9 175
2020	No data	9 247
2021	No data	9 327

Table 4: Estimated UAE population figures

	Water Usage	
Year	**Con-sumption**	**With-drawal**
2012	1 462	4 651
2013	1 474	4 745
2014	1 547	4 838
2015	1 612	4 931
2016	1 627	5 024
2017	1 672	5 002
2018	1 697	5 088

Table 5: UAE water usage figures

7.1.3 UAE Water Usage

Two metrics of water usage – consumption and withdrawal – were obtained from the UAE government and the United Nations FAO, respectively. The government dataset only provided values for 2012 to 2018; the same range was taken from the UN database (even though it had data for a longer time frame). Figures are in millions of cubic meters ($\times 10^6$ m^3). (Table 5)

7.2 All Data

Bold numbers are actual figures. Other numbers are forecasts based on the method described in the last row. The forecasts in *italics* are deemed invalid and incorrect. Cells shaded gray are redundant copies of existing data or missing data. Columns shaded in color are the various national water usage forecasts. Units are described in column headers. Mm^3, mega-cubic meters, means millions of cubic meters. (Table 6)

Year	Population (×1000)		Water Figures (Mm^3)		Consumption / Withdrawal per Capita (m^3)				"Population Method" Forecasts (Mm^3)			
	UAE Gov	UN	Consumption (UAE Gov)	Withdrawal (UN)	Consumption perCp Gov	Consumption perCp UN	Withdrawal perCp Gov	Withdrawal perCp UN	Consumption based on Gov	Consumption based on UN	Withdrawal based on Gov	Withdrawal based on UN
2010	**8 550**	**8 434**	1 374	4 538	-	-	-	-	-	-	-	-
2011	**8 947**	**8 530**	1 416	4 610	-	-	-	-	-	-	-	-
2012	**9 142**	**8 621**	**1 462**	**4 651**	**160.0**	**169.6**	**508.8**	**539.5**	1 462	1 462	4 651	4 651
2013	**9 198**	**8 709**	**1 474**	**4 745**	**160.3**	**169.2**	**515.8**	**544.8**	1 474	1 474	4 745	4 745
2014	**9 214**	**8 795**	**1 547**	**4 838**	**167.9**	**175.9**	**525.0**	**550.1**	1 547	1 547	4 838	4 838
2015	**9 263**	**8 877**	**1 612**	**4 931**	**174.0**	**181.6**	**532.4**	**555.5**	1 612	1 612	4 931	4 931
2016	**9 361**	**8 957**	**1 627**	**5 024**	**173.8**	**181.6**	**536.7**	**561.0**	1 627	1 627	5 024	5 024
2017	**9 487**	**9 032**	**1 672**	**5 002**	**176.2**	**185.1**	**527.2**	**553.8**	1 672	1 672	5 002	5 002
2018	**9 631**	**9 105**	**1 697**	**5 088**	**176.2**	**186.3**	**528.3**	**558.9**	1 697	1 697	5 088	5 088
2019	**9 771**	**9 176**	1 753	5 184	179.7	189.5	534.4	567.6	1 756	1 738	*5 221*	*5 208*
2020	9 891	**9 248**	1 795	5 256	181.4	191.6	540.0	574.8	1 794	1 772	*5 341*	*5 315*
2021	10 019	**9 327**	1 838	5 328	182.9	193.7	545.6	582.0	1 833	1 806	*5 466*	*5 429*
2022	10 148	9 425	1 880	5 400	184.4	195.6	551.2	589.3	1 871	1 843	*5 593*	*5 554*
2023	10 276	9 505	1 922	5 472	185.7	197.4	556.8	596.5	1 909	1 877	*5 722*	*5 670*
2024	10 405	9 585	1 964	5 544	187.0	199.2	562.4	603.8	1 946	1 909	*5 852*	*5 787*
2025	10 533	9 665	2 006	5 615	188.2	200.9	568.0	611.0	1 982	1 942	*5 983*	*5 905*
2026	10 662	9 745	2 048	5 687	189.3	202.5	573.6	618.2	2 018	1 973	*6 116*	*6 025*
2027	10 790	9 826	2 091	5 759	190.4	204.0	579.2	625.5	2 054	2 005	*6 250*	*6 146*
2028	10 919	9 906	2 133	5 831	191.4	205.5	584.8	632.7	2 090	2 036	*6 385*	*6 268*
2029	11 047	9 986	2 175	5 903	192.4	207.0	590.4	640.0	2 126	2 067	*6 522*	*6 391*
2030	11 176	10 066	2 217	5 974	193.3	208.4	596.0	647.2	2 161	2 097	*6 661*	*6 515*
2031	11 304	10 146	2 259	6 046	194.3	209.7	601.6	654.4	2 196	2 128	*6 801*	*6 640*
2032	11 433	10 227	2 302	6 118	195.1	211.0	607.2	661.7	2 231	2 158	*6 942*	*6 767*
2033	11 561	10 307	2 344	6 190	196.0	212.3	612.8	668.9	2 266	2 188	*7 085*	*6 894*
2034	11 690	10 387	2 386	6 262	196.8	213.5	618.4	676.2	2 300	2 218	*7 229*	*7 023*
2035	11 818	10 467	2 428	6 334	197.6	214.7	624.0	683.4	2 335	2 247	*7 375*	*7 153*
2036	11 947	10 547	2 470	6 405	198.3	215.9	629.6	690.6	2 369	2 277	*7 522*	*7 284*
2037	12 075	10 628	2 512	6 477	199.0	217.0	635.2	697.9	2 404	2 306	*7 670*	*7 417*
2038	12 204	10 708	2 555	6 549	199.8	218.1	640.8	705.1	2 438	2 336	*7 820*	*7 550*
2039	12 332	10 788	2 597	6 621	200.5	219.2	646.4	712.4	2 472	2 365	*7 972*	*7 685*
2040	12 461	10 868	2 639	6 693	201.1	220.3	652.0	719.6	2 506	2 394	*8 125*	*7 821*
2041	12 590	10 948	2 681	6 764	201.8	221.3	657.6	726.8	2 540	2 423	*8 279*	*7 958*
2042	12 718	11 029	2 723	6 836	202.4	222.3	663.2	734.1	2 574	2 452	*8 435*	*8 096*
2043	12 847	11 109	2 765	6 908	203.0	223.3	668.8	741.3	2 608	2 481	*8 592*	*8 235*
2044	12 975	11 189	2 808	6 980	203.7	224.3	674.4	748.6	2 642	2 509	*8 750*	*8 376*
2045	13 104	11 269	2 850	7 052	204.2	225.2	680.0	755.8	2 676	2 538	*8 910*	*8 517*
2046	13 232	11 349	2 892	7 124	204.8	226.2	685.6	763.0	2 710	2 567	*9 072*	*8 660*

2047	13 361	11 430	2 934	7 195	205.4	227.1	691.2	770.3	2 744	2 595	*9 235*	*8 804*
2048	13 489	11 510	2 976	7 267	206.0	228.0	696.8	777.5	2 778	2 624	*9 399*	*8 949*
2049	13 618	11 590	3 019	7 339	206.5	228.9	702.4	784.8	2 812	2 653	*9 565*	*9 095*
2050	13 746	11 670	3 061	7 411	207.0	229.7	708.0	792.0	2 846	2 681	*9 732*	*9 243*
Pred. Method	Linear extension	Linear regression	Linear regression	Linear regression	Power regression	Power regression	Linear extension	Linear extension	Population Method	Population Method	Population Method	Population Method

Table 6: Tabulation of all relevant national-level data and their projections up to 2050