POLITECNICO DI TORINO

Corso di Laurea Magistrale in Ingegneria Civile

Tesi di Laurea Magistrale

Urban water management and recycling: assessment of current practices and development of future economic projections

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Marzo 2020

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Introduction

Today, more than ever, dynamics of human interaction both among themselves and with nature are dictated by an economic-financial dimension that was born and nurtured on a linear Take-Make-Waste model. Far from having a moralistic intent, the paper would like to underline how, in this dimension, the yardstick is growth and profit, relatively unimportant figures if related to the concept of sustainability or better survival. Finance, an abstraction that should represent the complexity and interconnection of our planet, sins of pride in believing that roles are reversed, and that nature obeys rules written on paper by economists. As a consequence of capitalism, the social problem evident today is, unfortunately, the proof. What is measured inevitably becomes the unit upon which targets are set, the result are goals which are orphan of dimensions that have an impact, although not immediately apparent, potentially devastating.

Nature, intended as a system, is the definition of survival, and, as skillfully described by Taleb [Taleb, 2012] in a world dominated by black swans, nature is antifragile. The key attributes of complex systems, biological systems fall into this category, which grant its antifragile properties are redundancy and decentralization. These two terms strongly clash with the business mentality oriented towards growth and profit, where efficiency and economy of scale are seen to be the north star.

In this discussion, the problem of urban water management will be challenged with this approach.

Starting from the technical definition of urban wastewater in the first chapter, a second section will follow explaining how cities have in the past and are today dealing with this issue, from adduction and distribution, through collection, to treatment and disposal.
The third section consists of a future outlook in light of the rising demand in terms of both quantity and quality when facing a growing uncertainty and scarcity of the offer.

The state of the art of decentralized water treatment technology in the fourth section will end up arranging all the pieces which will star in the comparative model developed and analyzed in the fifth section.

The outline of the problem will attempt to reveal some black swans converting them to grey swans, and then the model will try to give robustness to tackle these and other uncertain scenarios. The red thread followed in the model, unrolls from the comparison between two key resources for our modern survival, water, and electricity. Given that these two worlds are closely related, and we cannot afford to lose either, we shall consider that power shortage would eventually result in a water shortage. Therefore, not building a robust power grid is not an option. On the other side water distribution infrastructure, as we will see in section two, requires significantly more physical space, ties up water resources in the cycle that could be implemented elsewhere, and relies on forecasts which inevitably lead to uncertainties finally resulting in inefficient use of economic resources.

Characterization of greywater

The wastewater caused by the needs of the people and their daily life activities, which originates from residential and small businesses such as schools and hospitals, is defined as domestic wastewater. Domestic wastewater is evaluated in two streams: greywater and black water. Generally, water from the shower, bath, washbasin, washing, and dishwashers is defined as greywater, and the remaining toilet water is defined as black water (Jefferson et al., 2000). The greywaters can be evaluated based on their pollution level: marginally polluted greywater and very dirty greywaters. Less polluted greywaters include shower and wastewater from the bathroom sink, very dirty greywaters include wastewater from the kitchen washbasin and washing machine (Birks and Hills, 2007). Greywater is the most significant percentage of domestic wastewater.

Greywater quality is function of various parameters starting from the quality of the supplied water in the first place, then considering its transportation to and from the place of usage and the contaminants that enter its flow during its use which are affected by household profiles determined by geographic location, social and cultural habits (e.g. type of chemicals used for cleaning activities), number of occupants and demographics. Pollution, net of other contaminants such as piping biofilm detachment during transportation, is a result of personal hygiene products, detergents, dirty clothes, and body contamination (Table 1). Ghaitidak and Yadav (2013) conducted research comparing the quality and quantities of greywater produced in 18 countries, categorizing them on an income basis. Quantitatively the low-income countries (LIC) produced less greywater compared to high-income countries (HIC); from a qualitative perspective, nutrient pollution was higher in LIC.

Greywater source	Pollutants
Washing machine	Suspended solids, organic matter, oil and grease, salinity, sodium, nitrate, phosphorus (detergent), bleach, pH
Dishwasher	Suspended solids, organic matter, oil and grease, increased salinity, bacteria and detergent, pH
Bath-Shower	Bacteria, hair, suspended solids, organic matter, oil and grease, soap, shampoo residues
Sink (kitchen included)	Bacteria, suspended solids, organic matter, oil and grease, soap, shampoo residues

Table 1. Greywater description

Characterizing quality of residentially produced greywater

Chemical parameters

Biochemical or biological oxygen demand(BOD) represents the quantity of O2 that is used in 5 days by aerobic microorganisms (inoculated or already present in a solution to be analyzed) to decompose (oxidize) the organic substances present in a liter of water in the dark and at a temperature of 20 ° C or of aqueous solution while Chemical oxygen demand(COD) represents the oxygen demand for complete oxidation through chemical means of both organic and inorganic substances. BOD_5 and COD measurements have limited significance if taken in absolute terms. For biodegradability purposes, even if COD usually is higher than BOD_5, their ratio matters overall. In fact, it determines the ease of bacterial decomposition of the organic matter, and as reported in literature is favorable (Li et al. 2009). Almost half of the organic matter can be processed if the ratio falls, as it most commonly does, between 0.31 and 0.71 which is an indication that almost half of the organic matter in greywater is (Halalsheh et al. 2008). Boyjoo, on the other hand, reported in 2013 ratios as high as 4:1. The lack of excreta, compared to other sources of wastewater is a threat to its biodegradability (Jefferson and Jeffrey, 2013) This imbalance is caused mainly by xenobiotic organic compounds (XOC). Other than reducing the degradability of greywater in the short-term, they pose a significant long-threat to the environment because of their high persistence that can last several years (Noman et al. 2018). These synthetic organic compounds are used as ingredients in skincare, pharmaceuticals, and household chemical products such as beauty products, bleaches, surfactants, and softeners. The presence of this pollutant can also be caused by both chemical and biological treatment of greywater that partially modifies the compound. Furthermore, if water containing XOCs is used unrestrictedly coming in contact with plants or animals, it can quickly accumulate in these organisms and subsequently pose an environmental risk (Fatta-Kassinos et al. 2011). Just by analyzing the ingredients of commonly sold cosmetics and detergents in Denmark, 900 potentially polluting XOCs were identified (Eriksson et al. (2002).

Relative and absolute values of nutrients such as nitrogen and phosphorus are another critical parameter to keep in mind during the evaluation of greywater. Greywater typically contains less nutrient compared to toilet wastewater. Nutrients such as nitrogen, phosphorus are important parameters, particularly high phosphorus-containing greywater.

Generally, nitrogen level in greywater is quite low because ammonia is a significant driver of this pollutant and the most significant part of household ammonia production is flushed in the toilet. Other household sources of ammonia are shampoo, cleaning products, and other household products. In countries where phosphorus-containing detergents are not prohibited, detergents used in laundry and dishwashers are the main source of phosphorus in greywater.

Where phosphorus-free detergent is used, the average phosphorus concentration varies between 4-14 mg / L. In countries where phosphorus-containing detergents such as Thailand are used, the phosphorus concentration varies between 45-280 mg / L (Moral et al., 2006).

The pH value indicates whether a liquid is an acid or a base. Generally, the pH value of high loaded greywater is higher than the pH value of low loaded greywater. The concentration of hydrogen ions(pH) is in the range of 6.4-8.1 (Boyjoo et al., 2013). Greywater generally has an alkalinity value in the range of 20-340 mg / L (Morel et al., 2006). Greywaters from kitchens and laundries produce the most alkaline effluent in the household.

Oil and grease concentrations varied between 37-78 mg / L and 8-35 mg / L, respectively (Moral et al., 2006). This pollutant enters the greywater flow from the kitchen sink and dishwasher. Important oil and grease concentrations can also be observed in bathrooms and laundries. Surfactants and other chemicals derived from household cleaning products and detergents used in washing and dishwashing machines are the main sources of surfactants in greywater. Depending on household characteristics, even personal cleaning products can play a major role. Therefore, concentrations of surfactants present in greywater strongly vary. Detergents are a group of chemicals that have cleansing properties, and these compounds have a polar hydrophilic group and a nonpolar hydrocarbon branch (hydrophobic) [Ying et al., 2006] which creates problems in the treatment phases.

Physical parameters

Total suspended solids (TSS) indicates a parameter used in water quality management and purification. It indicates the number of solids present in suspension and which can be separated by energetic mechanical means such as vacuum filtration or centrifugation of a liquid sample. It is sometimes associated with water turbidity measurements. Through an optical method of analysis, it is possible to determine, as both a non-specific and specific parameter, the level of turbidity of a liquid by exploiting the absorption and reflection of light rays of a specific wavelength. It is measured in NTU (nephelometric turbidity units) (fig 1)

fig. 1. turbidity standards for 5, 50 and 500 NTU [U.S. Geological Survey]

Food residues from the bathroom, laundry and kitchen, oil and solid particles and greywater lead to high solids content. These particles and colloids cause water to be blurred and can cause clogging in filters and pipes used in treatment. SS concentration in the high loaded greywater ranges from 29-505 mg / L, in the low-charged greywater, the range is 12-315 mg / L (Boyjoo et al., 2013).

There is a robust linear relationship between TSS and total dissolved solids in wastewater [Hannouche et al., 2011] on the other hand a correlation stands between TDS and electrical conductivity(EC) and Boyjoo [boyjoo, 2013] gives these numbers as characterizing of TSS and EC: The electrical conductivity and turbidity range are in high loaded greywater respectively; 190-3000 µS / cm, 19 -444 NTU, while in low charged greywater, respectively; 14-1241 μS / cm, 12.6-375 NTU values were measured (Boyjoo et al., 2013).

The temperature of the greywater is higher than that of the water source and varies between 18 °C and 30 °C. These temperatures, which are thought to be caused by the warm waters used for cooking and personal hygiene, do not adversely affect biological treatment processes (Morel et al., 2006). On the other hand, higher temperatures can lead to an increase in bacterial growth and precipitation in storage tanks.

Table 2 shows that wastewater from the shower and washbasin contains low concentrations of bacteria and chemicals, while wastewater from the kitchen sink contains high concentrations of bacteria, solids and chemicals and oils.

Table 2. Pollutant concentration in greywater from different sources

GW source	Commercial	Household not including kitchen sink				Household including kitchen sink				Less dirty GW	Very dirty GW
References	**Veneman, 2002**	**Eriksson, 2003**	**Winward et al., 2008**	**Casanova et al., 2001**	**Winward et al., 2008**	**Seigrist, 1980**	**Travis, 2008***	**Huelgas, 2009**	**Jong, 2010**		
BOD_5 [mg/L]	22-360	26-130	20-166	65	20-166	145-324	1042		23.5-392.4	59-424	48-890
COD, [mg/L]		77-240	73-575		73-575		2180	770-2050	119-3740	100-645	661-1815
TSS, [mg/L]	10-200	7-202	20-42	35		100-204	1250		72,5-4250	30-303	35-625
N(totale), [mg/L]		3,6-6,4	4,1-16,4		4,1 – 16,4		22	21,9-43,5			
NO3-NO2, [mg/L]	<1-17,5	<0,02-0,26	-					0,9-5,3		<0.1-15,0	<0,1-4,6
P(total), [mg/L]		0,28-0,78	-			2,8-7,8	3,8	2,9-14,5			
pH	5,3-10,8	7,6-8,6	6,6-7,6	7,5	6,6 – 7,6	7,3-8,7	5,7		7,02-7,86	6,4-8,1	5,2-10,0
Total Coliform [CFU/100ml]	2x10^2-10^5	6x10^3-3,2*10^5	$4x10^5$		$4x10^5$	2,4x10^7-3,8x10^8				$1x10^2$	$1x10^4$
Turbidity [NTU]			-							23-240	103-148
Faecal Coliform, [CFU/100ml]	3,5*10^4		1,8*10^4-8*10^6	5,6*10^5		2,1*10^7-2,5*10^7				10-10^5	10^2-10^6

*only kitchen sink

Furthermore, to understand the very high variability of quality based on different cultures and sources of effluent, table 3 reports the information gathered in literature showing, for different sources, where the data is available, the high variability on samples used to conduct characterizing experiments in those countries. Table 4 sets the parameters for the virtual synthetic greywater used in the model, the estimates consider also synthetic greywater parameters used in controlled studies that will be reviewed in the chapter regarding decentralized treatment.

Table 3. Pollutant concentration in greywater in different income level countries

Parameters	Low-income countries				High-income countries			
	India[1]	Pakistan[2]	Niger[3]	Yemen[4]	USA[5]	UK[6]	Spain[7]	Germany[8]
BOD_5 [mg/L]	100 - 188	56	106	518	86	39 - 155	-	59
COD, [mg/L]	250 - 375	146	-	2000	-	96 - 587	151 - 177	109
TSS [mg/L]	100 - 283	155	-	511	17	37 - 153	32	-
TDS [mg/L]	573	102	-	-	171	-	-	-
N_{tot}, [mg/L]	-	-	-	-	13,5	4,6 – 10,4	43779	15,2
NO3-NO2, [mg/L]	0,67	-	-	98	-	3,9	-	-
P_{tot}, [mg/L]	0,012	-	-	-	4	0,4 – 0,9	-	1,6
pH	7,3 – 8,1	6,2	6,9	6	6,4	6,6 – 7,6	7,6	7,6
Turbidity [NTU]	-	-	85	619	31,1	26,5	20	29
E. Coli [CFU/100ml]	-	-	-	-	$5,4x10^5$	10 – $3,9x10^5$	-	-

[1]Parjane and Sane (2011), [2]Pathan et al. (2011); [3]Hu et al. (2011); [4]Al-Mughalles et al. (2012); [5]Jokerst et al. (2011); [6]Birks and Hills (2007); Pidou et al. (2008); [7]March and Gual (2007), March et al. (2004); [8]Merz et al. (2007)

Table 4. Virtual synthetic greywater from each source

Parameters	Shower/Bath	Hand basin	Kitchen	Laundry
pH	7,4	7,2	6,9	9,1
BOD_5 [mg/L]	135	138,7	932,4	186,5
COD [mg/L]	357,9	340,5	1122,8	1545,8
TS [mg/L]	425,5	450,3	1468,4	586
TSS [mg/L]	122,7	89,2	398,7	141,2
TDS [mg/L]	287,8	473,3	633	710,4
TOC [mg/L]	65	60,8	542	189,2
TN [mg/L]	11,3	9	31,2	18,9
TP [mg/L]	1,2	1,1	48,3	19
Total coliform [CFU/100ml	$8,9x10^3$ – $1,9x10^6$	$8,7x10^2$ – $8,9x10^6$	$2,4x10^3$ – $1,3x10^5$	$1,1x10^3$ – $4x10^5$
E. coli [CFU/100ml	$1,1x10^4$	$1,1x10^4$	-	-

Greywater quantification

Consumption of clean water is hence substantially variable depending on geographic location. Quantifying total water consumption and as a consequence greywater production, in this setting, will concern mostly developed urbanized countries as the aim of this thesis is that of unveiling unsustainable consumption habits where water is today still available and saving measures to maintain the resource in terms of quantity and with acceptable quality. A breakdown of water consumption by micro components at the household level and how people habitually use them will provide the right weights with which to ponder the single source of pollution and compute total greywater pollution.

Water conservation's primary target is, for indoor uses, mostly aimed at reducing toilet flushing with potable water. This activity is, together with showering, the most water dispendious. In the total household consumption balance flushing accounts for around 30%. Each member of the household activates the flush an average of five times a day. Because the working mechanism is relatively simple, it does not break very often leaving even very old systems in place for a long time. The problem is that technology has advanced, and water waste is not an option anymore. Older toilets made between the 80s and the early 90s use in an average flush approximately 14 liters which brings the daily consumption up to 80 liters/day/person. While other toilets produced before the 80s utilize up to 30 liters per flush, today the alternatives offers range from single button activation like ultra-low flush toilets (ULF) and high efficiency toilets (HET), respectively consuming 6 and 5 liters, while dual flush toilets offer a further reduction to 4 liters per flush.

Differently from toilets, washing machines have a higher energy consumption associated with their use, and therefore people upgrade to newer versions to save on energy bills. Washing laundry in old machines requires more than 100 liters per cycle. Newer appliances, as well as consuming up to 65% less energy, require up to 40% less water, their consumptions decrease with increasing rating, A, A+, A++, A+++. Household size has a significant influence on positively reducing water consumption in washing machines. Often, these are run not at full load hence wasting both energy and water.

Showering activities account for a significant part of total consumption. Depending on shower duration and on flow rate, the total consumption can reach approximately 70 liters per shower. The EPA sets the maximum flow rate of the shower heads at 9,5 liters/minute. Significant savings can follow reductions in the showerhead flow rate and in the average showering time. The usage of low flow rate showerheads does not increase in a statistically relevant way the total shower time [Richard Critchley and David Phipps, Water and Energy Efficient Showers: Project Report, 2007]. Lower flow rate showerheads come in an array of sizes consuming from 3 liters/minute up to 6,6 liters per minute.

Cooking, washing hands, and brushing teeth result in a minor percentage of water consumption, but nonetheless, the activities brought out in the bathroom sink are lightly polluted and hence can be reutilized of water reuse. The flow rate of the faucets installed in the kitchen and in the bathroom are respectively 8 liters per minute and around 5 liters per minute. The faucet’s flow rate is can be reduced in the bathroom while in the kitchen this rarely happens because of the need to rinse plates and cooking utensils.

Similarly, to washing machines, dishwashers are also characterized by the consumption of both energy and water and technological improvements have brought them to consume always less of both resources.

Table 5. Daily per capita consumption

	Consumption	Selected consumption value	Consumption pattern	Partial consumption [L/day]	Relative consumption
Shower	5-9,5 [L/min]	9,5	8 [min/day]	76	37%
Toilet	4-14 [L/use]	14	4,5 [use/day]	63	30%
Washing machine	60-100 [L/use]	90	2 [use/week]	25,7	12%
Dishwasher	5-50 [L/use]	30	2 [use/week]	8,6	4%
Kitchen sink	8 [L/min]	8	1,5	12	6%
Bath tub	160 [L/use]	160	0,5	11,4	6%
Bathroom sink	2-6 [L/min]	5	2	10	5%
			Total consumption [L/day]	**206,7**	

To substantiate our hypothesis of consumption habits in developed countries, some examples of domestic urban consumption will follow. The United States is the undisputed leader of water consumption at household level. Thou total consumption varies significantly from one State to the next, indoor water use can be considered stable at 242 liters/day/person (Heaney et al., 2000). What makes the difference is the outdoor use of drinking water in gardening or leisure installations such as private swimming pools, which spike the consumptions well over 600 l/d/p. In European countries and Australia, the number drops between 150 and 200 l/d/p. The National Bureau of Statistics of China for 2018, reports consumptions varying significantly in rural areas while in urban settings the values are very similar to European countries with a per capita use of 181 l/d/p for domestic activities in Beijing and 202l/d/p for the nearby Shanxi province.

Appropriately weighing and combining table 4 and 5 we obtain the average concentration of pollutants in the model's virtual synthetic greywater used in the standard scenario(table 6).

Table 6. Daily per capita consumption

	pH	BOD_5 [mg/L]	COD [mg/L]	TS [mg/L]	TSS [mg/L]	TDS [mg/L]	TN [mg/L]	TP [mg/L]	TK [mg/L]	e-coli CFU/100ml
Selected effluent quality	7,4	135,4	356,1	428,0	119,3	306,8	11,1	1,2	2,9	110000,0

Once the unitary consumption has been determined, it is now necessary to understand how consumer behavior changes depending on the household size and its age distribution.

In literature, regarding consumption of necessary daily resources at household level, such as energy and water, many studies support a positive correlation between these parameters when considered in their entirety hence reducing per capita consumption (Arbués et al. 2006, Navajas 2009, Schleich and Hillenbrand 2009). Specific studies (Lyman 1992, Arbués et al. 2010, Morgenroth 2014) investigate more in-depth the effects of household size on water consumption and, also shed light on the effects of the age distribution of members dividing them in a younger class below 20 and above 65 years of age. Lyman's study suggests a further distinction between those family members aged less than 20yo but more than 10 and the newborn children up to 10 years of age. The results of the studies are reported in table 7.

Table 7. Household size influence on water demand

Size of household	Total consumption [L/day]		Per capita consumption [L/day]		Variation in per capita consumption [%]	
	Arbués, 2010	Morgenroth, 2014	Arbués, 2010	Morgenroth, 2014	Arbués, 2010	Morgenroth, 2014
1	184,5	173,6	184,5	173,6	–	–
2	264	275,4	132	137,7	-28,5%	-20,7%
3	332,6	330,3	110,9	110,1	-39,9%	-36,6%
4	399,8	390,8	99,9	97,7	-45,9%	-43,7%
5	483,1	442	90,9	88,4	-50,7%	-49,1%
6		526,2		87,7	–	-49,5%

As anticipated in the analysis of the micro components, a substantial reduction in consumption takes place thanks to combined uses of specific appliances, plateauing with families of five or more. Regarding the findings linked to consumption age discrepancies, the two authors, Lyman and Arbués, affirm that in urban settings, younger people tend to wash more because of their requirements and the increased time they spend at home as babies and young adults while the elderly have reduced social life and therefore use less water. Another explanation provided takes into account income levels, which are supposedly higher in younger households. While this could be the case, studies on correlations between income, price elasticity, and water consumption provide very dispersed conclusions agreeing only on the fact that there are some levels under which, regardless of the cost and the income of the household, water consumption does not go. For countries with scarce water resources, the World Health Organization (WHO) sets the standards for minimum water necessities per capita .The change in consumption in Arbués's economic model considers a reduction of 8,59% for older citizens and an increase in the younger urban population of 4,42%. While this distinction was made considering the age threshold of 20 years of age, Lyman reports that children, aged less than 10, are the main responsible for the increase consuming up to 2,5 more times the water of an average adult.

Given this consideration, the model in the last section of the thesis will consider Arbués's values for the population percentage aged between zero and fourteen.

Reuse Standards

For reuse standards, many countries and institutions have set parameters for the most relevant pollutants and have defined the scope of use of water with specific characteristics (table 8). What should be highlighted is that even where parameters have been set and therefore should be followed, in countries such as Italy that has a limiting parameter in almost every field, there is no recurrent control performed on those responsible for the reclaiming process. In fact, while other European countries like France and Greece impose control on a weekly, monthly, or annual basis depending on the risk associated with certain pollutants, many countries do not. It has to be said that operating these systems in countries that do not impose regular controls, requires nonetheless a permit given on a case to case basis [Alcalde 2014]. Due to the importance of water quality, to test greywater treatment technologies later discussed, the choice fell on the Italian guidelines because of stringent nature of these reuse standards.

Table 8. Reuse standards

Country / Institution	BOD$_5$ [mg/L]	TSS [mg/L]	Turbidity [NTU]	pH [-]	Chlorine residual [mg/L]	Micro-organisms [CFU 100/mL]	Purpose
USA[1]	≤10	-	≤2	06-Sep	≥1	Fecal Coliforms: non detectable	Unrestricted urban reuse
WHO[2]	≤10	≤10	-	-		Thermoresistant coliforms: ≤10	Toilet flushing
Canada[3]	≤20	≤20	≤5	-	≥0,5	E.coli: ≤200 Thermoresistant coliforms: ≤200	Toilet and urinal flushing
Germany[4]	<5	-	-	-	-	Total Coliforms: <100 Fecal coliforms: <10 *P. Aeruginosa*: <1	Service water
Japan[5]	≤20	-	not unpleasant	5,8 – 8,6	retained	Total Coliforms: <1000	Toilet flushing
	≤20	-	not unpleasant	5,8 – 8,6	≤0,4	Total Coliforms: <50	Landscape irrigation
Italy[6]	≤20	≤10	-	6,0 – 9,5	-	*E.coli*:<10	General
South Korea[7]	<10	-	<2	5,8 – 8,5	>0,2 mL/L	*E.coli*: Not detectable	Toilet flushing
Israel[8]	<10	<10	-	-	-	Fecal Coliforms: <1	General
China[9]	<10	-	<5	6 – 9	>1 (after 30 min), >0,2 (at point of use)	Fecal Coliforms <3	Toilet flushing
	<20	-	<20	06-Sep	>1 (after 30 min), >0,2 (at point of use)	Fecal Coliforms <3	Irrigation
	<6	-	<5	06-Sep	>1 (after 30 min), >0,2 (at point of use)	Fecal Coliforms <3	Washing

1: USEPA (2012); 2: WHO/UNEP, (2006); 3: Health Canada (2010); 4: Nolde, (1999); 5 Maeda et al., (1996); 6: Fountoulakis et al., (2016); 7: Jong et al., (2010); 8: Pidou et al. (2007); 9: Li et al. (2009b); Zhu and Dou (2018).

Centralized water cycle

In order to supply the quantities of water used form each household a man-made cycle, resembling nature's one, has been built with a distribution network connecting the abduction facilities with the households which, after using the commodity discharge it in the sewer system where grey, yellow, brown and stormwater end up combining forming blackwater channeled to treatment plants and then reintroduced in the cycle in different ways. (fig. 2)

In theory, if the treatment plants were to restore the same abducted water quality, the impact of our activities and water use would be minimal. In practice, all these components have a varying degree of inefficiency that result in a worrying trend of decreasing water quality and pollution of the reservoirs.

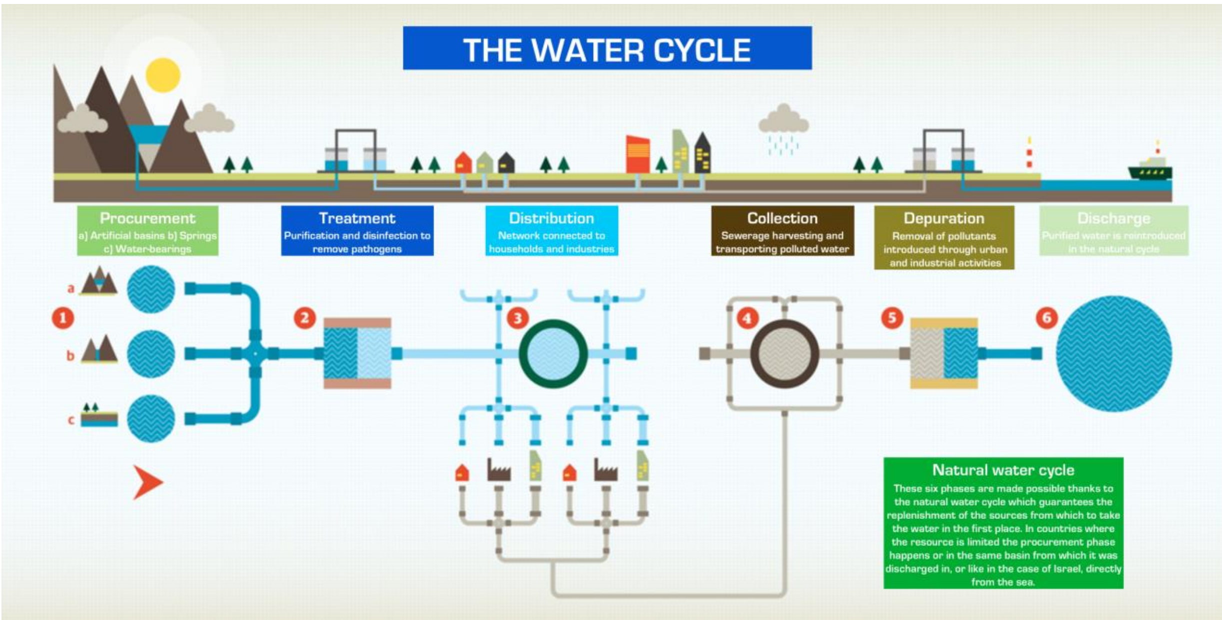

fig. 2 Flow diagram of a conventional supply network

Modern distribution network

The first phase goes through is the intake structure, where water is captured from the natural cycle. These works differ from each other depending on whether the water they capture is surface like rivers and lakes or underground springs and wells. Immediately downstream of the intake works, are the water treatment plants necessary to make them suitable for human consumption: water purification plant in case of capture of surface water and disinfection plants for groundwater.

The drinking water is made to flow by the supply pipes that work both under pressure and free surface flow conditions. Along the route of a pressurized feed pipe, various works of art are realized for their regular operation and maintenance.

The main ones are:

The drains: located in the most depressed points of the hydraulic profile. In the maintenance holes, made of reinforced concrete, a derivation is realized closed by a gate that, once opened, allows the emptying of the supply pipe. The drain water is conveyed, via a special pipe, into nearby ditches or collectors.

The vents: these are located where the hydraulic profile is highest. They can be free or automatic: free vents consist of a pipe, ending with a curved part called pastoral, connected directly to the adapter and of a height greater than the line of the hydrostatic loads (they are used in pipes with low internal pressures), while automatic vents are formed with a hydraulic device, air relief valve, equipped with balls, which, depending on the pressure in the duct, allow air to escape or close the duct. These vents are mounted inside reinforced concrete pits, branching off the main pipe and are preceded by a gate that allows their disassembly without interrupting the flow.

The vents can perform one or all three of the following functions:

Degassing function: this function eliminates the air that forms inside the pipeline during its exercise, the water drags it until the highest points of the duct where it is released. These air bubbles, if not eliminated, would form pockets that can assume such dimensions as to reduce the water flow until it is interrupted completely;

The volumetric function of emptying: during the emptying phases the vents allow the entry of a volume of air such as to compensate for the volume of liquid that escapes from the drains, thus avoiding dangerous internal depressions. The problems of depression can occur not only during regular management of a pipeline like emptying and filling the pipeline for maintenance but also for exceptional situations such as pipeline rupture with significant water leakage compared to the flow rate at full capacity or uncontrolled and accidental discharge operations of the pipeline;

filling volumetric function: during the filling phase of a duct, the existing air inside the empty pipes is released, thus avoiding the danger of the formation of air pockets.

Hydraulic break or disconnection works: they are made up of tanks of limited capacity, which are built whenever it is necessary to cancel the piezometric gauge in one point of the feeder, and not to submit one or more sections of pipeline to excessive pressures that are not compatible with the characteristics of the pipes used, both to allow the derivation of one or more pipes from the main duct, in this case we speak of dividers. In some cases, they are also used to allow the execution of hydraulic control measurements. Branch connections can also be carried out without the need to make dividers.

Accumulation works: they are large capacity tanks, built along the route of very extensive supply pipelines, in order to guarantee a water reserve, for a given period, in the sections downstream of the work in the event of flow interruptions in the trunk upstream.

Hanging sections: they are made for crossings of rivers, streams or unstable areas. They can be made with:

Self-supporting pipes: in the case of steel pipes, the single span cannot exceed
$40 \div 50$ m;

Actual bridges: the pipeline is carried by properly constructed bridges.

Underpasses are made to pass under roads, highways, railways, and small streams. Currently, no-dig technologies are used to install the pipeline, replacing trench excavation, to preserve the integrity of nearby buildings.

Collection

By sewer, more formally an urban drainage system we mean the complex network of generally underground tunnels, to collect and dispose away from civil and productive settlements the surface waters such as meteoric waters or those used to clean road, and wastewater from human activities in general.

The ducts, in general, work in free-surface flow conditions; in particular sections, depending on the altitude of the area to be served, their operation can be under pressure like in the case of pressing pipes departing from pumping stations, crossings, and siphons.

Urban sewage systems are, based on the water running in them, further distinguished in mixed sewage, collecting both urban wastewater and rainwater or a combination of separate systems can be in place. This solution divides black water and stormwater. Storm sewers are used solely for the collection and conveying of rainwater and water used to clean roads. Some systems also have devices separating the first rainwater, which is more polluted due to surface runoff and erosion.

The ducts, depending on the role they play in the sewer network, are distinguished according to the following terminology:

sewers: elementary canalizations that collect the water coming from the sewers connecting the utilities and the rainfall drains, conveying them to the collectors. [4 guarda sotto] It is good practice to use diameters not smaller than 200 mm for black sewers;

Collectors: ducts constituting the main framework of the network that receive the water coming from the most critical sewers and the flow originated through drains. The collectors then merge into an emissary;

Emissary: starting from the point where there are no more inflows, these unite the total flow from the network and transports the collected water to the purification plant. Often with the term emissary, we indicate also the effluent channels originating from the plants.

The hydraulics of the collection network

Depending on whether it is a mixed or separate type, it requires a different design approach. While in the first case it is necessary to take into account both the effluents supplied to the network by the various users, both civil and non-civil, and the precipitations that may occur in the region considered, in the case of separate sewers these two aspects must be considered separately.

The average value and the maximum value are the two key parameters that have to be considered in order to build an appropriately sized network. Generally, the sewer pipe must be sized based on the average flow rate complying with the permissible speed parameters during "steady-state" operation, but must also be able to dispose of the maximum flow rate without problems such as overflowing from the gridded pits at street level spread along the way. In this case, it is admitted that the recommended speeds for the sewage trunk can be exceeded for short periods.

It is for this reason that usually in residential areas of medium-large dimensions or in areas affected by frequent flooding or meteorological events of exceptional dimensions, the solution to separate networks is chosen. This avoids unnecessary over-dimensioning of the ordinary network during operation for "civil" uses and creates a dedicated network to compensate for the inconveniences associated with heavy weather events in cities.

In mixed systems, the collectors are sized according to the meteoric flow rates, which are prevalent with respect to the waste ones at the maximum project events. Since the duration of rainy periods is relatively short, most of the time the collectors are affected by black water only, with frequent problems of too little speed, and the consequent possibility of sedimentation of solids and the potential triggering of putrefactive anaerobic processes. For this reason, for mixed manifolds, sections other than the circular one are used so to allow adequate speed and water height during dry periods without creating problems in times of heavy rainfall accommodating the extra flow in the wider region of the section like ovoidal sections.

Relatively to sanitary or black sewers, the flow calculation depends on the following parameters:

Population (P): forecast of the population to be served during the life of the sewer (40 - 50 years). It is calculated using a formula, such as that of compound interest or the logistic function or calculations based on the Pearl index, based on the data coming from the censuses.

Water supply (S): expressed as liters/person/day, it normally represents the amount of individual water that must be guaranteed on average during the year. This value is usually indicated by the General Regulatory Plans;

Maximum consumption coefficient (m): it represents the ratio between the peak flow rate on the day of maximum annual consumption and the average annual flow rate. This coefficient is taken as 2.25 and is given by the product of 1.5 * 1.5. The first coefficient is the ratio between the average flow rate on the day of maximum annual consumption and the average annual flow, the second between the peak flow rate on the day of maximum annual consumption and the average flow rate on the day of maximum annual consumption. In practice this value varies with the size of the built-up area, it grows with decreasing extension of the urban center because of the effect of time;

Reduction coefficient (r): coefficient that takes into account the effective rate of distributed drinking water which is discharged into the sewer after use: it is given by the ratio between the actual discharge into the sewer and the theoretical one calculated based on the water supply. In fact, the domestic discharge flow rate is connected, but not coincident with that distributed by the urban water distribution network. The differences can be determined by causes such as water uses that do not involve discharges into the black sewer like watering the garden and washing the streets, or losses in the distribution network. Therefore, not all the water that is introduced into the distribution network reaches the users and then from these is conveyed into the black sewer. In the design practice for this rule coefficient, a variable value between 0.7 and 0.8 is assumed.

Storm sewers

For the sizing of the storm sewers, we refer to the maximum rainwater flow that is calculated on the basis of the hydrological study of the duration of meteoric events, of the extension of the areas of the drainage basins and the soil absorption coefficients. Statistical methods are taken into account to determine the flow in different areas.

The storm drains are generally sized for low values of the return time, T = 2-10 years. Since T is much less than the useful life of the work equal to about 40-50 years, in practice, it is accepted that the drains are insufficient during some exceptional rains, of intensity higher than the project one, with consequent leakage from the wells of the line of the conveyed water. On the other hand, in order to avoid any occasional flooding, the return time T should be increased to an economically unacceptable level, therefore to contain the costs of the work it is preferred to accept this risk which does not involve loss of human lives as in the case of dam and damage to property as in the case of canals.

Obviously, in the case of mixed sewers, both flows must be considered for appropriate sizing.

Treatment

Considering the great variance due to geography and other influencing factors, the substances to be eliminated in wastewater can be divided into sedimentable and non-sedimentable. The first substances are solid and heavier than water, and therefore, they easily go to the bottom when the flow stops or the speed falls below a specific limit.

The non-sedimentable substances partly float and partly remain in the liquid. These are dissolved or in the colloidal state; the colloidal state can be considered an intermediate state between solution and suspension.

In a medium-strength exhaust, the total solids (expressed in mg/L) can be classified with the first division between suspended and filterable solids averaging a 3:7 ratio, and these categories can be further divided on the basis of their chemistry and behavior(fig. 3) as follows:

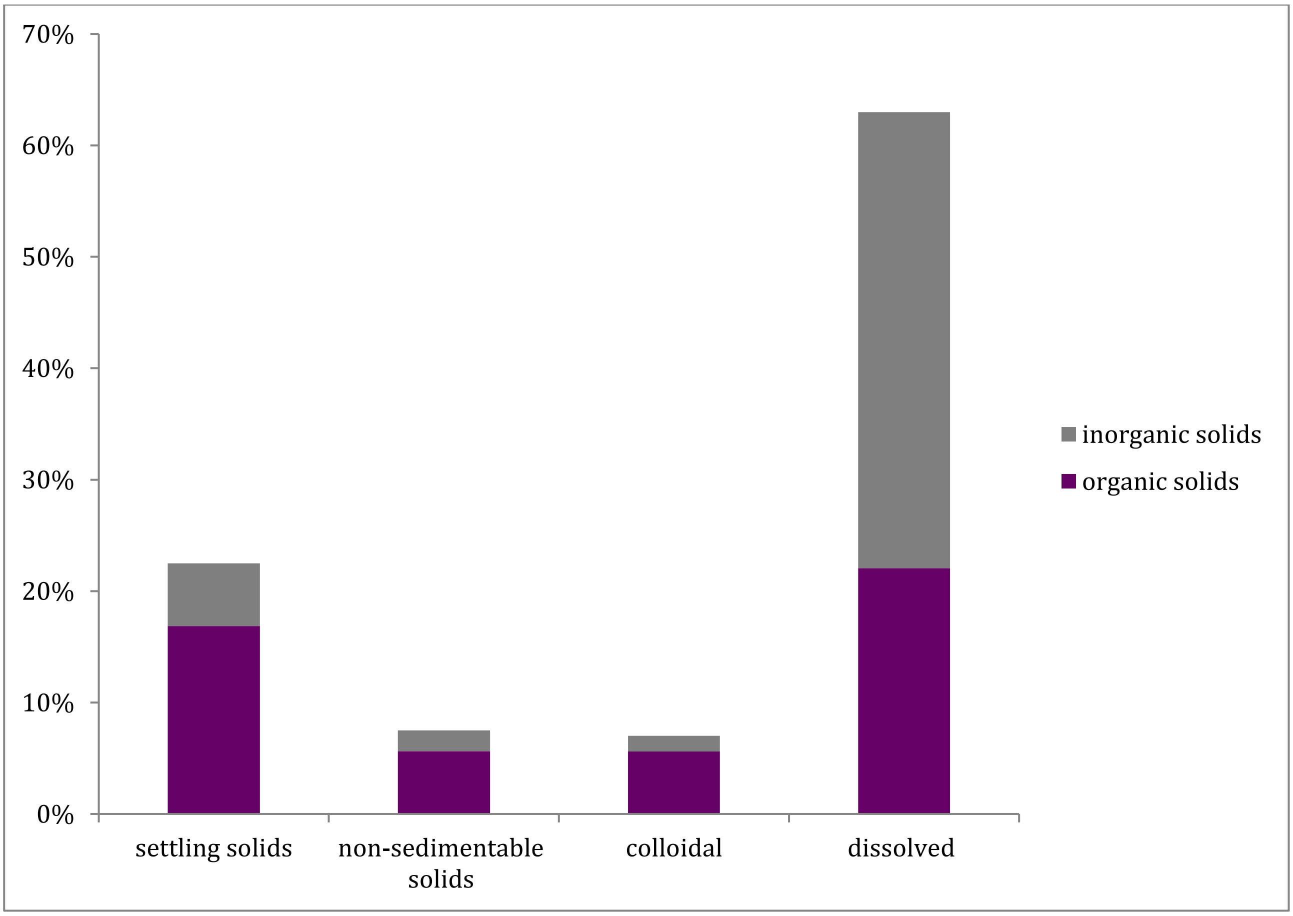

Fig. 3 average pollutant concentrations (Simmler)

Usually in a wastewater treatment plant there are two specific lines:

the water line;

the sludge line.

In the water line the raw sewage coming from the sewers is treated and as a rule includes three stages:

Pretreatment or primary treatment: a physical process used to remove sedimentable organic substances contained in the slurry. Includes grilling, sandblasting, degreasing and primary sedimentation;

Biological oxidative treatment and secondary treatments: a biological process used for the removal of sedimentable and non-sedimentable organic substances contained in the slurry. Includes aeration and secondary sedimentation:

Tertiary or advanced treatments: they are all those treatments carried out upstream or downstream of biological oxidation, they allow to obtain a further refinement of the degree of purification. It includes special treatments to reduce the content of those substances that are not eliminated during the first two treatments.

In the sludge line, the sludge separately is treated during the sedimentation phases foreseen in the water line. The purpose of this line is to eliminate the high quantity of water contained in the sludge and to reduce its volume, as well as to stabilize (render rot-proof) the organic material and to destroy the pathogenic organisms present, to make the final disposal less expensive and less harmful to the environment.

The final effluent treated or clarified wastewater is conveyed into a pipeline called emissary, with final delivery to the surface waters, aquifer recharge or other artificial or natural reservoirs. If the final effluent has specific characteristics, it can also be used for irrigation or in industrial processes.

Furthermore, treatments that are carried out inside a purification plant can also be classified based on the nature of the pollutant removing force:

mechanical treatments: this type includes the preliminary operations of removing undissolved solids, they rely purely on physical or mechanical principles;

Chemical treatments: by adding specific substances, these treatments rely on chemical triggers initiating reactions that facilitate precipitation or disinfecting. Neutralization belongs to this class of treatments and is used to change the water's PH.

Biological treatments: they are based on biological processes by microorganisms present in the water. Each type of organism has a specific metabolism that is used to target dissolved solids in water.

The mechanical pre-treatments include the following operations and account together with primary sedimentation to approximately 8% of the total energy expenditures of wastewater treatment plants and from a chemical standpoint remove approximately 3% of pollutants:

Screening/sieving is a coarse mechanical filtration operation that has the aim of retaining non-sedimentable coarse solids like rags and plastic and solid sedimentable coarse such as gravel. If not removed, these could easily accumulate and create obstructions in pipes, pump impellers, or obstruct the mixer shaft.

The grit removal is especially useful in the case of unitary sewers (sanitary + storm) for the removal of soils and other inorganic materials with a diameter d> 0.2 mm present in suspension in wastewater such as pieces of glass and metal, pebbles and in general all heavy and abrasive materials which are conveyed into the sewer, through rainfall drains, together with meteoric water. They are necessary to avoid inconveniences such as abrasions in mobile mechanical equipment like pumps, clogging of pipes and channels, accumulations in the digesters and hoppers of the sedimentation tanks due to the presence of sand in the wastewater.

Degreasing is introduced in the purification cycle, downstream of the grids and sand traps, oils and fats are present in the wastewaters sometimes in quantities such as to negatively influence the subsequent treatments, especially regarding biological treatments. Oily substances tend to coat the biological materials with a thin veil, thus preventing their contact with O2 and therefore limiting their oxidation, equalization, and homogenization.

Equalization and homogenization are usually positioned at this point because the inlet of the purification plant has a variable capacity both in terms of water volume and pollution load. Therefore, the sewage can be subjected to a treatment of equalization, to level the flow tips and homogenization, to level pollution peaks.

In order to guarantee the desired efficiency of the subsequent purification treatments, the liquid manure is required to have sufficiently stable parameters in terms of flow rate and organic load especially when the biological processes are highly sensitive to the variability of the BOD_5 concentration. In this case, the sewage is fed into a tank, made of reinforced concrete, of such capacity as to guarantee the damping of hydraulic peaks and extreme organic loads. This accumulation tank is placed downstream of all other pre-treatments and is sized to ensure a suitable residence time for the slurry. During the stationing in the tank, the wastewater undergoes an energetic stirring treatment, which guarantees the homogenization of the sewage, and aeration, to prevent the onset of septic conditions. The equalization tank can also act as a sand trap. The insufflation of a small amount of air generates a sufficient mixing motion that avoids suspended organic deposits in the slurry, although allowing the sedimentation of the sand. The equalization and homogenization tanks can be placed either along the wastewater flow line and then fed with the entire flow to be treated or off-line to receive only the rate exceeding the maximum flow rate that can be treated by the system. In this case, a suitably sized spillway is placed along the sewage flow line. Lifting the water after each treatment is almost always necessary and is done by employing a pump. The first four treatments reported (indispensable) are positioned upstream of the actual purification processes and allow the removal of materials and substances which by their nature and size risk damaging the downstream equipment and compromising the efficiency of subsequent stages of treatment.

Primary sedimentation consists of tanks in which the decantation is carried out for the separation of sedimentable suspended solids (SSS) obtaining a reduction of BOD_5 around 30%, the removal of the remaining 70% is left to the subsequent biological treatment.

Biological oxidative treatment

The biological oxidative treatment consists in the biodegradation by micro-organisms of all the organic substances present in the water to be purified, until they are transformed into substances that are simpler and harmless from an environmental point of view. This treatment is nothing more than an extension of the self-purification that takes place spontaneously in the waterways, operated, in the case of the treatment plant, in an environment in which certain optimal conditions are artificially maintained in order to concentrate and accelerate the ongoing process. From an economic perspective, this is the most energy-demanding part of the treatment procedures accounting for up to 52% of total energy consumption. In this process, approximately 67% of chemically polluting parameters are removed.

The active sludge or oxidation tank is the fundamental basin for biological purification, here the microorganisms that oxidize and degrade the organic substance which is suspended in solution as mud flakes. To activate these microorganisms, water is continuously oxygenated and mixed from dispensers placed on the bottom of the tank. After a particular time in this tank, suitable for the degradation of the organic substances and for the nitrification of the ammonium ion to nitrate, the mud is sent to a secondary sedimentation tank which separates the activated sludge, containing the microorganisms that carry out the purification biological, from the clarified wastewater that has undergone the biological purification process. During this phase, there are numerous biodegradation reactions of biodegradable organic matter, where complex organic substances are converted into simpler inorganic substances, such as CO_2, H_2O, NH_4^+, NO_2^- NO_3^-. This process requires a delicate balance in the strength of the aeration process. The internal turbulence of the wastewater due to the oxygenation of the tank must not exceed a certain level to avoid the destruction of mud flakes and the consequent death of the micro-organisms that inhabit it. In practice, it is necessary to try as much as possible to oxygenate the oxidation tank, while seeking, at the same time, not to destroy the mud flakes and the microorganisms present within them. Furthermore, parameters such as pH and temperature need to be monitored to sustain the life of the microorganisms: reasonably neutral pH between 6 and 8, a dissolved O_2 concentration greater than 2 mg/L temperatures between 25 ° C and 32 ° C, avoiding letting them drop too much during winter.

MBR

Membrane bioreactors represent an advanced purification technology compared to the more common traditional activated sludge technology.

The MBR system combines a traditional biological process with activated sludge, with the membrane separation process, generally microfiltration or ultrafiltration, which replaces the secondary sedimentation system.

The membrane bioreactors, based on the positioning of the filter unit with respect to the biological compartment, are classified as SMBR or classical MBR. In the submerged membrane configurations the membranes are immersed inside the oxidation tank in direct contact with the wastewater, through a self-priming pump, a slight depression inside the filtering module forces the treated effluent to pass through the membranes and an efficient separation of solids, retained on the outer surface of the membranes, from the filtered water is obtained without further sedimentation and refining treatments. The most common scheme is that of external membranes or external circulation; the membranes are external to the aeration tank. The effluent from the oxidation tank is pumped into the membrane filtration module. The retained part is returned to the oxidation tank.

MBBR

The Moving Bed Biofilm Reactor is formed by tanks of biological reactors, in which the microorganisms anchor on dispersed support means and are suspended in the wastewater subject of the treatment.

The biofilm that forms on these supports is a function of the organic load associated with the incoming wastewater.

Unlike other adherent biomass processes, the supports, in this case, are free to move and therefore do not keep the mutual or fixed positions relative to the reactor. The biofilm that forms on these supports is a function of the organic load associated with the incoming wastewater.

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The growth of a biofilm on a support is the result of the interaction between biological processes and substrate transport processes.

In particular, biofilm formation is mainly due to the growth of microbial cells and the production of extracellular polymers, in general the contribution of the suspended mass that takes root on the support itself is negligible. Therefore the development of the film varies according to the composition of the wastewater and the transport processes. The availability of substrates for microorganisms within the biofilm depends on them. The progressive thickening of the film influences the diffusion of organic substrates and oxygen while, at the same time, depending on the hydrodynamic characteristics of the reactor, it causes the partial detachment of the films from the supports. In particular, this happens for several reasons: predation by organisms such as protozoa or metazoa, shear forces induced by the flow of water tangential to the film, and spontaneous detachment or collapse when the deep zones of biofilm limit the substrated oxygenation.

RBC

The Rotating Biological Contractor uses a similar film technology. The disks are immersed, 40% of their diameter, in a tank where the sewage flows continuously. While rotating, the microorganisms deposited on the disc forming a film of organic material progressively increases the layer's thickness. During the rotational motion, the film saturates with oxygen during the exposure phase to the air, then dives to adsorb and metabolize the dissolved and colloidal organic substances present in the slurry.

The film continues to develop until it reaches maximum thicknesses of 2–5 mm, to then detach autonomously, in the form of sedimentable flakes, facilitated by the cutting action induced by the resistance to rotation of the disc in the wastewater. Wastewater transports the detached film which is then

eliminated in the secondary settling phase.

Newer technologies such as the last two described have overall better pollutant removal performances and have the possibility to be introduced modularly in expanding existing treatment plants.

Secondary sedimentation follows the oxidative phase and has the task of separating the biological sludge from the rest of the clarified or treated wastewater. In fact, after an appropriate time of stay in the oxidation tank, the biological or active sludge passes to the secondary sedimentation where, by sedimenting, they separate from the treated or clarified wastewater. On the bottom of the secondary sedimentation tank, the sedimented biological sludge accumulates, while the clarified wastewater which is lighter, is located near the free surface. Secondary or biological sludge is different from primary sludge which is separated from raw sewage without undergoing any transformation by bacteria. After biological treatment, the sludge produced presents filamentous mud flakes that, interfering with one another, cause the sludge to behave differently from Stoke's Law expressing the maximum settling velocity of sediments.

The settled biological sludge (sludge line) can take various roads: it can be pumped back into the oxidation tank, it can be pumped partly into the first sedimentation tank to improve the characteristics of the primary sludge, it can be pumped into the denitrification tank or into the dephosphorization tank otherwise it can undergo thickening, digestion, and other treatments aimed at disposal according to the law.

Nutrients represent a significant pollutant in wastewater, regulations regarding phosphorus and nitrogen are stringent because of eutrophication mechanisms that they would trigger once the water reaches natural basins. Treatment for nutrients can be performed before or after the biological oxidation treatments. These account for 30% of polluting load[*] and 21% of energy consumption, approximately 9% denitrification plus 12% dephosphorylation.

Clariflocculation

In clariflocculators, the properties of some substances called "coagulants" are exploited, which in certain operating conditions allow the separation of suspended colloidal substances in the waters to be treated through their precipitation.

The various coagulants act according to their own particular and complex chemical-physical mechanism, but which however leads to the destabilization of the colloidal substances that once destabilized, should tend to precipitate. In many cases, even with a fair dosage of coagulant, precipitation does not occur, or if this would involve a considerable waiting time, then a "coagulation adjuvant" or "flocculant" is added after the coagulant which promotes further destabilization of the particles colloidal and especially the agglomeration of destabilized particles that can then precipitate easily. This process allows, depending on how it is performed: clarification of treated water, precipitation of some metals, reduction of COD and BOD, dephosphorization, removal of oils and fats. In fact, through this process the oily emulsions are broken dissolved in the water to be treated, allowing them to return to the surface and then de-oil it).

The whole process of clariflocculation can, therefore, be divided into coagulation, which involves destabilization of the colloidal substance and flocculation which is the agglomeration of destabilized particles in micro-flakes and then in coarse flakes that can settle.

From a plant engineering point of view, the process starts in a coagulation tank, and then the effluent passes through a flocculation tank to end up in a sedimentation tank.

Dephosphoratization

This process can happen in two ways:

Chemically during clariflocculation where precipitation is favored by adding chemicals such as calcium hydroxide $Ca(OH)_2$ or aluminum sulfate $Al_2(SO_4)_3$ that form insoluble compounds with phosphorous that are then caught by filters. This modus operandi, while simpler, has high variable costs connect to the chemical additives used to form the required compounds.

Biological removal of phosphorus, on the other hand, has both an anoxic and aerobic stage. It leverages phospho-accumulating heterotrophic bacteria which, if stressed in a combination of anaerobic and aerobic environments, accumulate way more phosphorus than they need. In the following stages, these bacteria sediment and are then removed.

Nitrogen removal

In wastewater treatment plants inlet, nitrogen can be present under four different forms: organic, ammonia, nitric, and nitrous nitrogen. The most significant part is constituted by ammonia NH_4^+, while in order to remove the nutrient efficiently, ammonia has to be transformed to nitrate NO_3^- through a preliminary nitrification process. In fact, in aerobic conditions and in the presence of O_2, there is the biological oxidation of NH_4^+ to NO_2^-, nitrite, and NO_2^- to NO_3^-.

Denitrification happens next and its a biological process carried out by some bacteria which consists of the conversion of nitrates NO_3^-, into nitrogen gas N_2. This process takes place under "anoxic" conditions [Simmler]. The bacteria responsible for denitrification are anaerobic heterotrophic bacteria including Pseudomonas aeruginosa, Pseudomonas denitrifcans, Paracoccus denitrificans, Thiobacillus denitrifcans. These bacteria also require organic substances to carry out their metabolism: the missing electrons will be provided by the organic carbon. Because of the oxidation process taking place during secondary treatment, organic carbon tends to run out. For this reason, it is preferable to have a denitrification tank in the head or upstream of the oxidation tank whose content recirculates towards the denitrification tank. In this way, the denitrification tank contains both the wastewater that has not yet undergone biological oxidation, therefore containing abundant quantities of organic carbon and the wastewater that has undergone biological oxidation, thus containing the nitrates to be converted into nitrogen which is suitably recirculated in the denitrification tank.

Disinfection

Wastewater disinfection serves to eliminate pathogenic microorganisms and parasites from contaminated water, already subjected to secondary treatments. Disinfection is certainly essential in case sewage comes from hospitals, sanatoriums or nursing homes, whenever the effluent flows directly into a receiving body of water whose waters are suitable for bathing or for recreational use at a distance not sufficiently precautionary.

Even for industrial and agricultural irrigational use of the effluent when contact with plant personnel is unrestricted. The methods commonly used for water disinfection include the addition of oxidants such as chlorine dioxide (ClO_2), molecular chlorine (Cl_2), sodium hypochlorite ($NaClO$), ozone (O_3) or treatment with ultraviolet rays.

Even if nowadays very debated because of its toxic residues, chlorine in various forms played a huge role in the safe distribution of water during the last century. Epidemiological studies on chronic diseases reported an increasing risk due to exposure of various chlorine disinfection by-products regarding bladder and colon cancer. Chlorine has a powerful oxidizing action, it oxidizes both some inorganic ions and organic substances with the formation of organo-halogenated compounds such as chloramines, aromatic and aliphatic chlorinated derivatives. These exert a powerful bactericidal action and destruction of viruses, blocking vital activities of microorganisms. In order for chlorine to effectively activate its function, adequate contact time, around thirty minutes, with the water to be disinfected is required.

Sodium hypochlorite does not require special precautions, is corrosive, is easy to use, costs more than chlorine, slightly changes the salinity and pH of the water, forms haloforms like chloroform and organic halogen derivatives, and is used for medium-small installations due to storage and supply problems. Despite the simple use and the excellent results obtainable, the application of this type of disinfection inevitably implies the formation of harmful halogenated organics and this usually does not allow compliance with the strict regulatory limits for residues.

Chlorine dioxide is, at atmospheric pressure, a rather unstable gas; for this reason, it is produced in the plant starting from chlorine gas (Cl_2), and from sodium chlorite ($NaClO_2$). The formation of ClO_2 can lead to the risk of explosion if the reaction conditions are not adequately controlled. Chlorine can also be used as a supporting substance in treatment with ozone, in fact, as mentioned earlier, chlorine's edge is that it can guarantee that disinfection is maintained even in later stages of the water cycle. While it has no residues and contact time is shorter, the high cost of using this substance is a potentially limiting factor. The high costs are caused by the fact that it must be produced on-site using ozonators prior to blowing it in the sewage.

Ultraviolet (UV) light is electromagnetic radiation with a wavelength between 100 and 400 nm that acts at the cellular level on the DNA of the microorganisms preventing their replication. The rays have an energetic bactericidal action and are rapidly absorbed by the solutions which make it effective in clear solutions but poses not applicable when the solution is opaque. There is no organoleptic alteration of water, but the destruction only affects the exposed bacteria and not those nested in microscopic organic particles rendering a pre-filtration necessary which only increases the already high costs of the technology. Ultraviolet radiation is generated by mercury lamps that emit with a wavelength (k) of 253.7 nm, which coincides with that of DNA absorption. Compared to other disinfection methods, UV has considerable advantages: it does not imply the presence of dangerous chemical substances to handle or monitor; there is no formation of unwanted by-products; UV systems are very simple to install and maintain. On the other hand the UVs do not have the persistence characteristic necessary to prevent recontamination downstream of the treatment, a characteristic that becomes important in the case of agricultural reuse with irrigation on crops destined for raw consumption. In this regard, the use of adjuvants such as the peracetic acid (PAA) dosed upstream of the lamps could be considered. PAA is an organic peroxide, obtainable from the equilibrium reaction between acetic acid and hydrogen peroxide, which is proposed as an alternative to traditional chlorine derivative disinfectants, since, despite the quantities used are high, the is no formation of toxic by-products. Other main advantages related to the use of peracetic acid are its broad spectrum of action against microorganisms, the low toxicity towards animal and vegetable organisms, and high efficiency and effectiveness of action even in the presence of organic substances. Operationally there is also the possibility to convert plants that use hypochlorite in PAA plants because of the similar contact times with the water. However, the use of peracetic acid has always posed serious problems of management, handling, storage, and compatibility with materials due to its instability and acidity. This acid tends to decompose over time, releasing considerable amounts of oxygen, causing risks for the operator's safety due to possible emanations of highly irritating vapors and the risk of tank explosion. Furthermore, the highly acidic characteristics of PAA pose a serious problem for metal corrosion, eye irritation, and also has an unpleasant smell.

Energy prospective

In these next paragraphs, we will analyze various data sets providing information on wastewater treatment plant's energy consumption. We will then review some of the cogeneration techniques that allow large plants to work with such efficiency and, based on some solid figures, finally discuss the pros and cons of centralized WWTP.

Huge concerns for both natural and economic resources lies in how the water cycle is powered. While water is something we cannot live without, energy is the other side of the coin. In light of today's real climate change threat, it is our duty to balance resource consumption sustainably.

In Europe, WWTP's energy consumption accounts for more than 1% of the total. The number of treatment facilities rose significantly to today's almost twenty-three thousand after the 91/271/CEE directive imposed that every city or town used one. The total energy consumption within the EU is estimated at 15.021 GWh/year. Although the Water Framework Directive's (2000/60/EC) objectives in terms of water safety have been achieved, most of the plants that have been constructed in the process are now aging and keep having unsustainable energetic consumption patterns. What may be a simple comparison between consumptions is complicated significantly by the great variety of configuration during the design phase and in the actual operating procedures. The first attempt to develop a systematic approach to evaluating the energy performance [Longo et al., 2016] selected as the basic KPI kWh/kg COD removed. Collecting data from over 430 WWTPs provided the researchers with evidence about some of the effects of design attributes such as plant size and most importantly the technology implemented and factors deriving from the operational dynamics such as dilution factors and flow rates. In fact, while traditionally energy consumption in WWTPs was expressed in kWh/m3 or kWh/PE, with reference to volume or units of population, utilizing these KPIs may lead to incorrect benchmarking because some basic assumptions do not hold. The pollutant load of the influent actually varies significantly, and even the water quality of the effluent differs of a certain degree. Furthermore, introducing the possibility of diluting wastewater makes the uncertainty grow even higher.

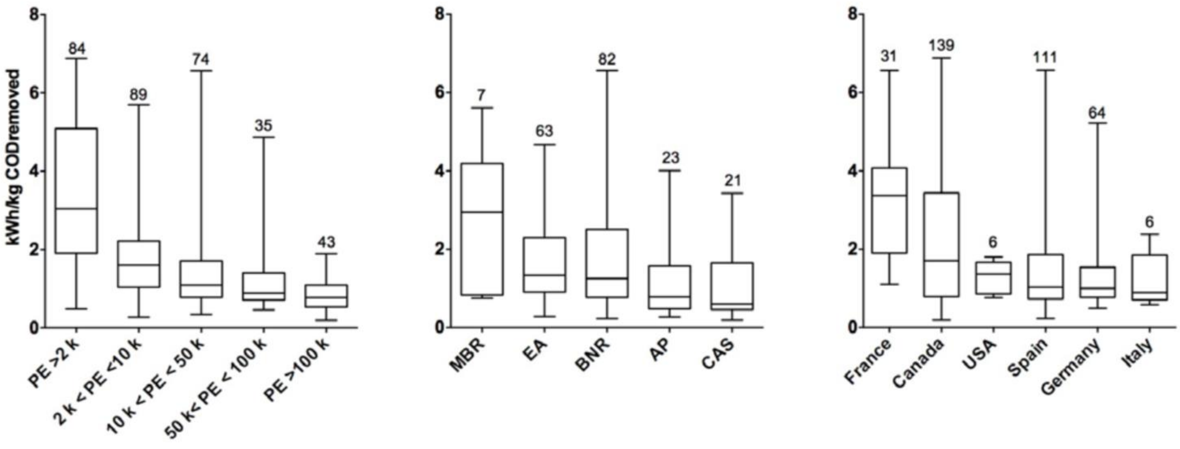


fig. 4 [Longo et al., 2016]

The first graph shows the relation between volume in terms of population equivalent and energy consumption. This substantial decrease in consumption is explainable by a variety of factors such as economies of scale, equipment efficiency that is usually higher for larger equipment like pumps and compressors that together with the whole plant are run in stable conditions with no peaks in power demands. Larger plants are also staffed with better trained personnel who improve the plant's efficiency.

The same sample was then divided based on the technology adopted in the plant. The lower intensity of treatment used with the Conventional Actived Sludge(CAS) technology makes it more efficient in this type of classification but, as mentioned in the previous part of this second chapter, there are far more elements to consider when comparing technologies in wastewater treatment. The difference in treatment efficiencies for the various technologies is what mostly causes the variable distribution showed in the third graph. Because of economic and environmental conditions, some countries may adhere to a particular technology or may have built the majority of their WWTP over different periods and having today to deal with aging for some structures.

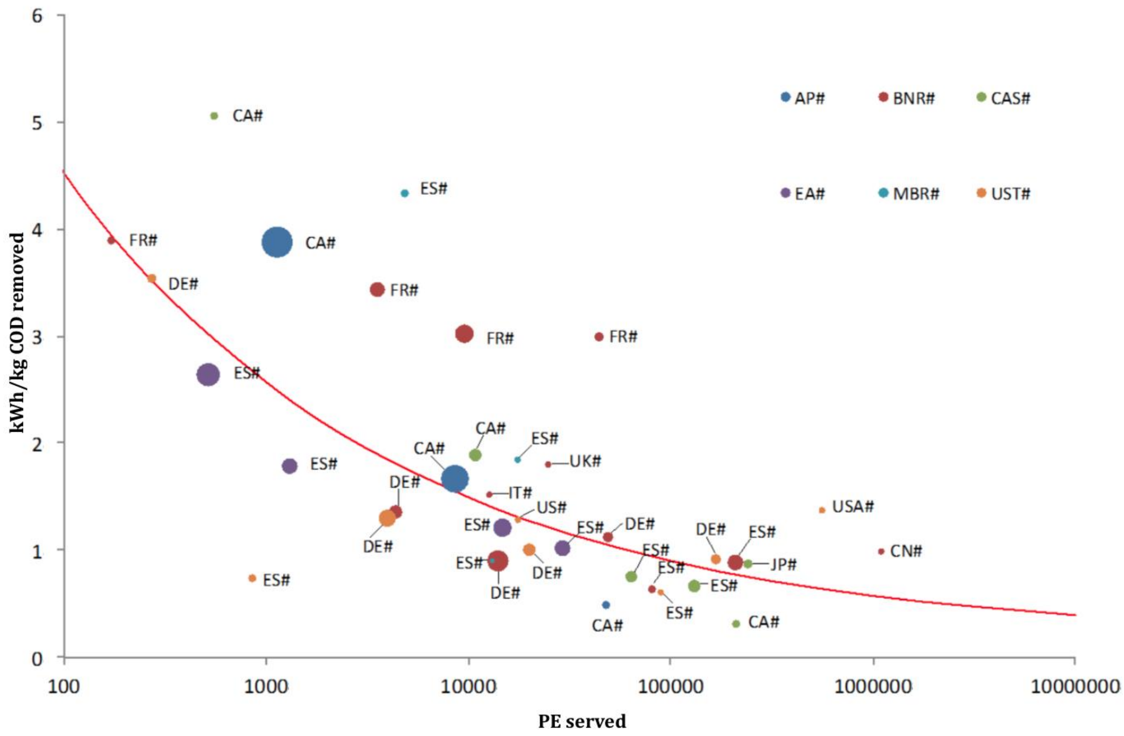


fig. 5 Plotted consumptions of WWTP divided by technology and country of operation [Longo 2015]

Figure 2 further highlights the great variability of the technologies and their efficiencies and leave room to consider qualitatively other factors, such as the price of electric energy, which influences energy consumption significantly among the various countries. In some countries it could be more economically viable to build a less efficient WWTP because of self-sufficiency in energy generation and hence low prices(i.e., France), other like Italy for instance, have the reverse situation and hence energy efficiency becomes a competitive advantage on the market (Liu et al., 2012).

With this said, in the model that will constitute the heart of this paper, in order to compute consumptions of centralized WWTP and decentralized treatment technologies, our primary KPI will be kWh/m^3. Our aim is to understand water flows and how to effectively convey water and get the most out of this precious resource. The point is that while for benchmarking purposes the measurements and comparisons made in terms of kWh/ m^3 are biased mostly by stormwater because in Europe mixed sewers are very diffused, at the end of the process, what really interests us and where I think we as society can be more efficient, is in avoiding diluted water or at least limit the amount of unused water to enter the treatment network. In an business setting, we could compare water to cash and inventory. In the business world, working capital is an index to which businesses pay very close attention. In the water cycle, the role of water is the same. Once water is used at the household level, it has to undergo a very long process keeping it "stuck" in the collection network or the treatment facilities and later in the distribution ducts. Therefore, the least amount of time water is in the cycle between the reservoir and the user's location, the less water, or cash in the comparison, are required to run the system. This becomes especially relevant for those countries that have little availability in the first place; they are a bit like small business startups that cannot afford to have their money stuck in working capital because of their limited resources. So, considering performance in terms of kWh/ m^3 will provide us with the information we want.

Rough estimations report that more than 2% of the world's electrical energy is used to supply and treat raw water (Olsson, 2012; Plappally and Lienhard, 2012). The US Environmental Protection Agency in 2013 estimated that 3-4% of total energy use in the US, with states such as California ranging between 7% and 15%, is devoted to drinking water provision and treatment. At municipal level, the percentage of energy consumed for these purposes rises to 30-40%, and if we consider a steady-state scenario regarding how we handle water in urban environments, this number is projected to increase of 20% in the next 15 years due to tighter regulations on drinking water parameters and population growth.

Energy consumption both in raw water treatment and subsequent supply process varies significantly across world regions. In countries where freshwater is available, it is taken from free surface reservoirs or pumped from groundwater and then conventionally treated. Some countries such as Israel, for instance, suffer from severe water scarcity and therefore have to use seawater. Desalinization is an extremely energy intensive process making it viable only when and where it is strictly necessary, an overview of energy consumptions of various available technologies is provided in *fig.6b*. Energy consumption for water supply is also significantly variable with increasing consumptions in already developed nations such as Germany and the US in which the infrastructure is old and leakages are important sometimes north of 30%.

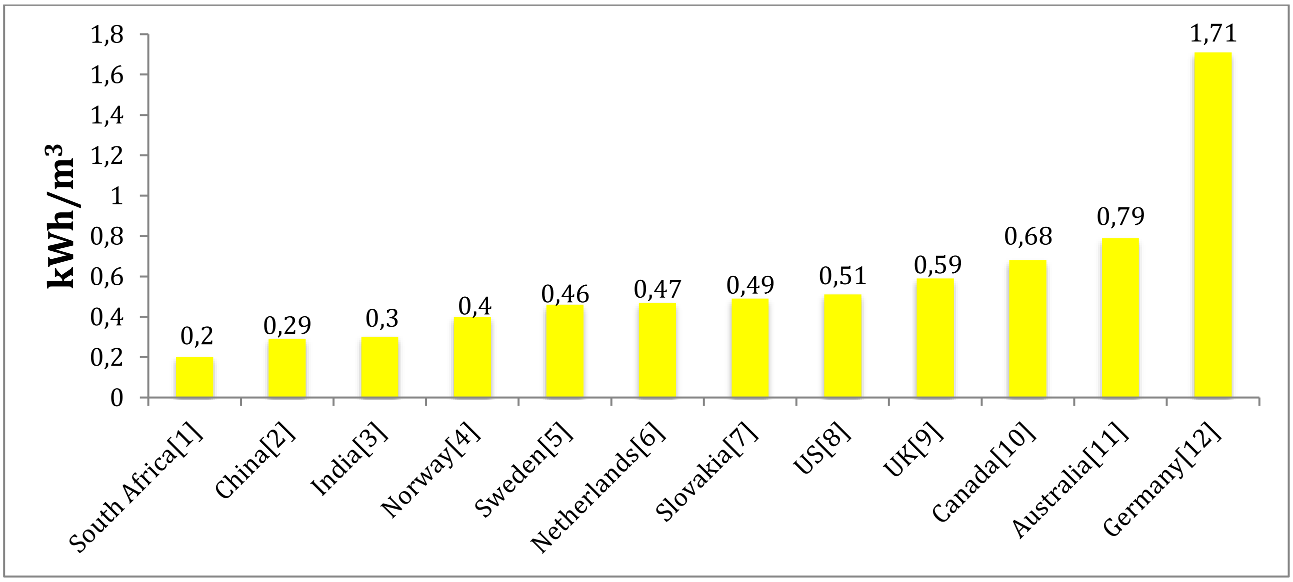


fig. 6a Energy consumption for water supply

[1] Buckley, 2011, [2] Smith et al., 2015 [3]Miller et el., 2013 [4]Denktash, 2011 [5&6] Olsson, 2012 [7]Bodik, 2013 [8]Kenway et al., 2008 [9] Rothausen, 2011 & Olsson 2012 [10] Friedrich, 2002 [11] Kenway 2008 [12] Meda, 2012

Properties	**MSF**	**MED**	**MVC**	**TVC**	**SWRO**	**BWRO**	**ED**
Typical unit size (m^3/day)	50,000–70,000	5,000–15,000	100–3,000	10,000–30,000	Up to 128,000	Up to 98,000	2–145,000
Electrical energy consumption (kW h/m^3)	2.5–5	2–2.5	7–12	1.8–1.6	4–6 with energy recovery	1.5–2.5	2.64–5.5
Thermal energy consumption (MJ/m^3)	190–282	145–230	None	227	None	None	None
Equivalent electrical to thermal energy (kW h/m^3)	15.83–23.5	12.2–19.1	None	14.5	None	None	None
Total electricity consumption (kW h/m^3)	19.58–27.25	14.45–21.35	7–12	16.26	4–6	1.5–2.5	2.64–5.5, 0.7–2.5 at low TDS
Product water quality (ppm)	≈ 10	≈ 10	≈ 10	≈ 10	400–500	200–500	150–500

fig. 6b Energy consumption for both brackish and sea water desalination [Al-Karaghouli et al., 2013]

As mentioned above, for the purpose of comparing these centralized infrastructures, it is necessary to determine a comparable figure in kWh/ m^3 of wastewater treated. Examining a wide variety of WWTP data from around the world, it appears clear that the range is wide because of many different factors. Nonetheless, it is safe to say that modern plants have, thanks to more advanced technology, higher efficiencies resulting in lower energy consumptions, more effective measures to recuperate thermal and chemical energy from sludge and gasses produced as a by-product during wastewater treatment.

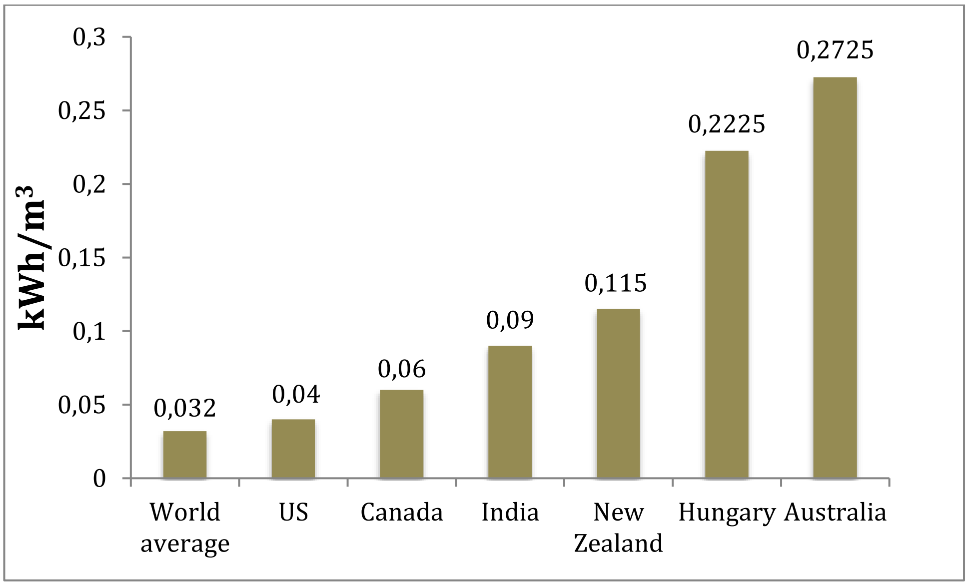


fig. 7 Energy consumption for water collection (Rana et al,. 2016)

One thousand four hundred of America's wastewater treatment facilities utilize Energy Star's portfolio manager and hence constantly provide data on which they are evaluated. The energy use intensity (EUI) of this data set ranges from less than 0,4 to more than 4 kWh/ m^3 across all wastewater treatment plants, the median has a value of 0,76kWh/ m^3 and a negative skew with those in the 95th percentile, using nine times the energy, 2,8kWh/ m^3, of those in the 5th percentile, 0,23 kWh/ m^3. For some WWTP the amount of water treated is fairly low and therefore, once the business has the initial costs of the plant it is antieconomic to take a step back and lose on the investment made. The scattered distribution can be attributed to both variations in terms of equipment efficiency and operational practices as well as to location specific conditions such as climate. The flow rate compared to the WWTP also has effects with some plants using as little as 50% of their design capacity due to oversizing for economic convenience. In this data collection, the range has an average of 10 million liters a day with bigger plants treating more than 200 million liters per day. For each phase of the water treatment line, primary secondary and tertiary, the percentages change substantially within the same countries. Canada's primary treatment consumption, for instance, can shift of one order of magnitude for 0.02kWh/ m^3 to 0.1kWh/ m^3 [Kneppers et al., 2009].

Secondary treatment accounts for the largest percentage of energy consumption and depends on many factors the most significant of which are a combination of technology utilized, pollution level, flow rate, and climatic conditions. Tertiary treatments are even more energy intensive with consumptions in the range of 0.4-0.5 kWh/ m^3 [EPA, 2008].

Important to note are also the trends of these consumptions that, especially in rapidly growing countries such as China, have increased substantially together with the number of WWTP over the last decade from a value of 57.1% in 2006 of total wastewater treated in plants to 93.4% reached in 2016. [Niu, 2019].

Studies have revealed that cities always focus more on the construction of WWTPs rather than on pipeline network deployment. Consequently, in most areas, diluted wastewater because of combined pipelines is the main reason for the low COD influent concentration (Fan et al., 2016. Specifically, southern China has a developed river system, high groundwater table, and poor pipeline quality; hence, groundwater often infiltrates the sewage network, which reduces the influent COD concentration. The pollutant removal rate is known to be closely related to energy consumption (Yang et al., 2008). As a proxy of the pollutant removed, the amount of wastewater treated is easy to measure. Thus, ECI m^3 is widely used as an indicator of energy efficiency for WWTPs (Kneppers et al., 2009; Mizuta and Shimada, 2010; Bodik and Kubaska, 2013; Garrido et al., 2013; Silva and Rosa, 2015). Longo(2016), sates that ECI m^3 increased with the COD concentration of the influent, which indicates that WWTPs receiving wastewater with higher COD concentrations have higher ECI m^3. What is important for this paper, in light of the last consideration, is that greywater contains a significant COD concentration which is treated almost entirely by decentralized units and therefore will also have a further benefit for centralized treatment efficiency.

As mentioned earlier, distribution pipeline leakages are a major problem and represent a high cost. This lost water falls into the category of Non Revenue Water (NRW). IWA provides material to understand where the water ends up. Many factors affect the growth of NRW in both developed and developing countries. Ranging from social/behavioral reasons such as water theft to technical issues like water meter inaccuracy, we will analyze in this section, physical problems leading to NRW. Today, the analysis of available data through research shows a common factor in breakages linked to the pipe's material. A Chinese study, collocates iron galvanized pipes as the ones that are most responsible for leakages followed by the ones made of polymeric material and lastly asbestos pipes [Jing et al.,2002] . Directly correlated to the pipe's material is the lifetime of the network, usually galvanized pipes has a life expectancy around fifteen years while polyethylene ones on average have one more year compared to iron ones. The main problem regarding age of pipes is that, because of the maintenance cost of the infrastructure these pipes are usually kept in place longer then they were supposed to and as a consequence, the leakages increase in a non-linear way up to staggering values of 50% of total water loss [Schouten and Halim, 2010].

This problem could be partially dealt with preemptively in the design stages of the infrastructure. In fact, the diameter of the pipes has both a direct and indirect correlation with the leakages. The increased thickness of pipes with a larger diameter is better protected by physical and chemical problems, and as a consequence of their larger diameter, the pressure in these ducts is lower hence tapering with another significant issue. Pressure is the driver of leakages; it is imposed by the needs of the structures that the network was built to supply. While is there is a leak a higher demand worsens the situation, pressure also has structural importance and sustains the weight carried from the buried infrastructure. Modern leakage detection methods, because of high variability in demand in time and space, try to identify pressure points that can create significant damages. The problem associated with pressure is linked to the speed at which it changes, the physic principle is commonly known as the water hammer hit, and it is caused by abruptly changes in pressure that block the water flow. In a network, all the connections make this a very complex problem to solve. Softwares such as AFT Impulse or Hytran are used to analyze the network data and solve problems before they cause breakages. Other ruptures can be caused by external forces such as works done in the surrounding area that exert pressure on the pipes causing them to brake. Corrosion is another major case, it is usually combined with one of the previously cited phenomena because, while corrosion can happen through all the pipe's thickness, it is more realistic to assume that corrosion weakens specific parts of the pipes and as an external force is applied the weaker section will bear all of the strain and break. Mechanisms of corrosion happen both from the contact between the pipes and the environment but also from the inside from what is called cavitation corrosion [Novak, 2005]. this phenomenon involves the creation of bubbles in the network when pressure drops and explosion when it rises again of the same bubbles in the flow or directly on the pipe's surface with a substantial amount of force that sometimes literally rip off small metal particles [Siegenthaler, 2000].

Based on R. Liemberger and A Wyatt the global average of NRW is 77 liters/day/person. This figure varies substantially across the globe from values as low as 36l/d/p for Australia and New Zealand and grows to 119l/d/p for Northern America reaching 152 l/d/p in Central Asia.

An increase in the consumption of both water and energy in light of future growth is a significant threat to the whole cycle's sustainability. Assessing how the cycle works and the energetic evaluation lead the way for the next chapter where, after a future outlook on population and urban environments setting future demand, the energy-water nexus will be furtherly investigated.

Future outlook

At the international conference "Planet Under Pressure" the threat represented by full force urbanization was quantified by forecasting that by 2030 new cities will have been built with an equivalent area of those of France, Germany, and Spain combined. If we continue charging forward without a change in paradigm, we are doomed. Circular economy is one of the most used terms today, and the European Union seems very determined to adopt this mentality in every aspect of its interactions. This approach mimics nature and if done correctly, provides us humans with a chance of surviving. While this would be great if achieved all together, the implementation has to be driven by more down to earth parameters, at least in the starting phases.

Just as chemical behavior follows the Gibbs free energy rule, human society settles in the most convenient state in light of its objectives. While chemical reactions have to happen, we as humans choose to act based on our shortsighted interests, an individual's lifetime cannot be compared to the number of years we have been inhabiting the planet. Nonetheless, our extinction in the next generations is a realistic possibility if we do not start moving fast.

This section describes the future in light of the growth in population and its distribution on the globe. The analysis highlights critical facts from the spreadsheets and graphs published by the United Nations divisions regarding population and urbanization together with data from other reliable sources. The premise of this discussion must underline that the projections are subject to high uncertainty levels resulting in population projections extending until 2100 while urbanization figures up to 2050 with more detailed data ending in 2030. Furthermore, the relation between energy and water is investigated, and the premise for the idea behind the model of the fourth chapter will be laid out.

Population

Population projections are very useful for policymakers to assess future demand for limited resources and understand which major trends may affect social and economic development in order to intervene effectively.

Demographers build these projections on three fundamental assumptions: fertility, mortality, and migration rates. Although done by experts, these numbers hide a degree of uncertainty that must always be kept in mind. If the assumptions hold, then the projection in terms of size quantification and age and sex distribution stands. A variety of sources concur to growing the projection's uncertainty: the starting point is already an estimate and the extension in time of the projection builds on the past inaccuracy and further adds errors by compounding uncertain figures.

Drivers of population change: fertility, mortality, and migration.

Assumptions on how the current rates of births, deaths, and immigration and emigration will change in the future serve as the driver of the projections. Based on these three crucial assumptions, age- and sex-specific population increases or decreases over the projection period are computed and added to the starting estimation or census.

Because of different assumptions both on the starting point and on the driving rates usually projections calculated by different entities on the same geographical region vary, therefore it is common practice to express the likelihood of a particular scenario to provide the reader with useable data. The United Nations Population Division(UNPD) also develops a set of different scenarios by changing the assumptions to show other likey situations

Fertility

Population growth is highly dependent on the future of fertility; when considering fertility, a key figure is the replacement rate of 2.1. Total fertility rate (TFR) measures how many children a woman will give birth to in her lifetime. Of the three underlying assumptions, fertility often has the most significant impact on changes in population size; this is true, especially where birth rates are high as in the developing countries. The theory followed by demographers is that rates will eventually stabilize around the replacement level in all world regions. What has to be understood of the so-called replacement level is that once a population drops below this rate, it does not stop growing immediately. Brazil serves as an example of having its ratio go below 2.1 in 2004 and still having, based on UNPD, a projected population growth until half of the current century. We can observe that combining this ratio with the fact that people are living longer and that there are effectively more people that generate the ratio, gives us a deeper understanding of the direction and that the ratio alone doesn't provide the inertia that a population may have at the end or the beginning of a specific period.

Given the close relationship between fertility levels and state of development of a country, meaning that least developed countries(LDC) have a high TFR, usually above 4 and that in highly developed countries(HDC) the rate has been well under 2.1 for quite a while, population projections are strictly correlated to economic factors and therefore suffer from a higher degree of uncertainty. To better express this, when projections are published, they usually come in sets of threes with a low, medium, and high fertility variant. These numbers are based on historical trends in populations that have already undergone the developing stage. Furthermore, extrinsic factors can strongly offset projections, policies regarding health and education can invert the trend in both directions.

Diving into the data,(fig. 8 and *table*9) fertility trends are in a steady decline with a global trend set to settle from today's average of 2.5 to 2.2 in 2050 and, always according to the medium variant projection, stabilize under the replacement rate by 2100 with the value of 1.9. While around the world many developed countries have already suffered a high reduction in fertility, Sub-Saharan Africa will be the last one to touch the 2.1 replacement level only in 2100 after a long and steady decrease. In the 30 years from 2020-2050, the births in LDC are set to increase by 38% meaning that there will be 1.1 billion new babies in places where health care, nutrition, and education is far from being a certainty.

The two main assumptions in this projection regard the likelihood of a continued decline in highly fertile countries and the fact that countries with low TFR will remain at current levels. The first assumption rests on factors such as increased education for women and girls, increased urbanization, women's empowerment in society and labor force which will mirror the decline in fertility experienced by countries who have developed earlier. The numbers expressed in the *table* 3** represent the medium variant which, depending on the international community's adherence to its commitments, can overestimate the decline in fertility if policies are not effectively enacted, or conversely underestimate it if an accelerated expansion to family planning information and services is granted. The second assumption is somewhat of a first-timer in human history because rates as low as 1-1.5 have never been recorded. In fact, even in these countries, there is a gap between desired family size, which is of two children, and actual size achieved because of contradicting factors such as parenting versus the demand of achieving higher education and building a career, the gender imbalance at household level or the absence of affordable high-quality childcare. While in LDC we can assume a behavior similar to ours in earlier stages, in HDC the same cannot be said, and therefore we can hypothesize that the trend will go towards filling the gap between the actual family size and the desired one. This seems plausible in the long run even thanks to government policies and programs looking to rebound fertility trends.

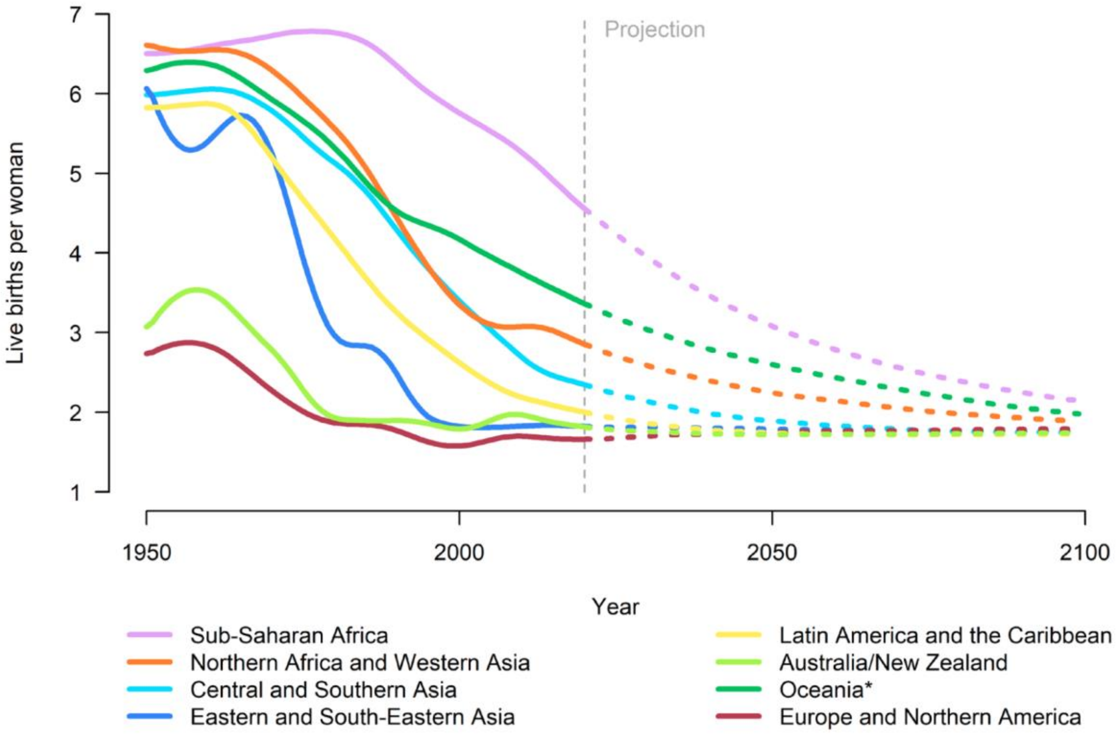


fig. 8 Past estimations and projection showing the total fertility considering countries grouped in Social Development Goal (SDG) regions.

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

Table 9 Total fertility rates. Average number of Live births per women

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

Region	**1990**	**2019**	**2050**	**2100**
World	**3,2**	**2,5**	**2,2**	**1,9**
Sub-Saharan Africa	6,3	4,6	3,1	2,1
Northern Africa and Western Asia	4,4	2,9	2,2	1,9
Central and Southern Asia	4,3	2,4	1,9	1,7
Eastern and South-Eastern Asia	2,5	1,8	1,8	1,8
Latin America and the Caribbean	3,3	2,0	1,7	1,7
Australia/New Zealand	1,9	1,8	1,7	1,7
Oceania	4,5	3,4	2,6	2,0
Europe and Northern America	1,8	1,7	1,7	1,8
Least developed countries	6,0	3,9	2,8	2,1
Land-locked Developing Countries	5,7	3,9	2,7	2,0
Small Island Developing States	3,2	2,4	2,1	1,8

Mortality

Demographers consider three main variables that affect mortality rates: infant mortality, impact of HIV, and increase longevity in life expectancy. Extraordinary events such as wars, natural disasters, due to their high unpredictability are not considered in projections, even problems such as obesity, due to the lack of data still cannot be factored in.

The effect of mortality in projections varies strongly based on the age distribution of a population: where the population is young, and infant mortality rates are high, a decrease of said rate will strongly impact the total projection, vice versa in more developed countries mortality concerns the older generation who have already gone through their lifecycle and therefore mortality has less of an impact. For instance, HIV had a very negative effect during the 1990s because it strongly affected countries with high TFR and a very young population. To give an idea of the impact of this disease, in 2019 life expectancy for people from Southern Africa, including South Africa, Botswana, Lesotho, Namibia, and Eswatini is 63.8 years, approximately the same number as in 1990 before the HIV/AIDS spread. In 2004 this number dropped ten points, this means that thirty years had to be devoted to regaining lost ground and further slowing down the country's development. The effect of this disease will be still relevant for several decades, nonetheless UNPD, thanks to continued investments aimed at giving access to antiretroviral treatment and limiting new infections, projects a significant decline in mortality linked to HIV.

Migration

Economic, social, political, and environmental changes are highly uncertain, migration is the result of these changes and therefore is even harder to estimate in projections. To further complicate the situation, reliable historical data is not always available. What is therefore assumed by demographers is a recurring pattern between LDC and HDC. This comes in "help" of developed countries where, as mentioned before, fertility is well below replacement rates and thanks to net migration gains, the population keeps on growing. In fact, in developed countries, half of the population growth in the new millennium can be attributed to migration. Many factors affect migration trends, and computing them in models is very complicated. Just as an example of the complex dynamics, UNPD's current projection shows migration to stop by 2100 all over the globe, which is arguably likely.

Data for the 2010-2020 decade shows a substantial decrease in emigration trends for regions such as Latin America, Western, Eastern and South-Eastern Asia with between 40 and 50% less population loss due to migration if compared with the previous decade. The same can be said for Northern Africa with a reduction of 48% in emigration. Nonetheless receiving countries such as Europe and Northern America have seen only a 16% decrease in entries in their countries.

Regarding the overall computation, of nine countries who experience positive net migration, in only five of these (Italy, Russia, Germany, and Belarus) the number was sufficient to offset the negative increase in natural deaths, and so the total population kept on growing. On the contrary, for Japan, Hungary, Ukraine, Estonia, and Serbia, this positive influx only slowed the effect of population decrease.

Projections

Up to date projections from the United Nations Population Division provide with an accuracy of 95% the global population size for the year 2030, 2050, 2100 with assessments ranging respectively between 8.5 - 8.6 billion, 9.4 - 10.1 and 9.4 - 12.7. As explained earlier, these projections are the result of calculations based on the three assumptions of fertility mortality and migration, which are evaluated via statistical methods.

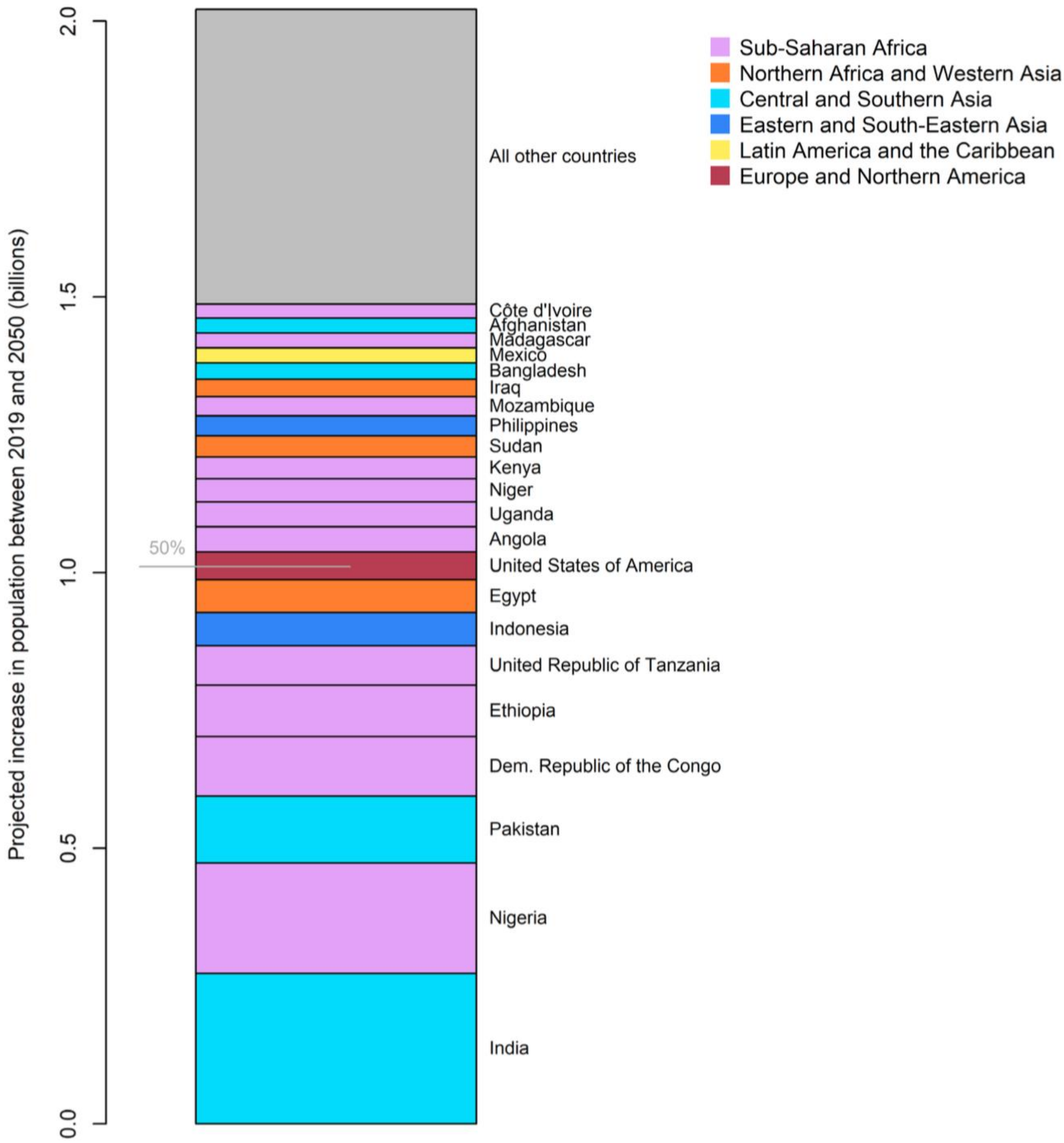


fig.9 country's marginal contribution to population growth between 2019 and 2050

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

What must be noted is that, as shown in figure 9 most of this growth (52%) will come from the Sub-Saharan regions becoming around 2062 the most populous region on the planet. This growth will be supported by the current young generation, which is now entering its reproductive years. Current age structure in regions is set to be the engines of growth, and even if the TFR in regions with numbers above 4 were to fall under replacement level immediately, population growth would nonetheless continue for several decades. This growth inertia due to our population age structure limits the short term effectiveness of policies to control fertility levels, but these are nonetheless necessary otherwise the problem will be just delayed with harder choices for future generations. Growth in LDC is furthermore another burden for regions to carry. Niger, for instance, is set to triple its population by 2050 and with gross national income below 1000 USD, the situation is complicated. While at first population growth in developing countries strikes for its adverse effects like the increased burden on low-income families, there is the so-called demographic dividend from which these countries will benefit. For demographic dividend we intend the period in time in which, due to the natural aging of a very young population, take Sub-Saharan regions as an example, the majority of inhabitants enter the productive part of their life between 25 and 64 with the result that the workforce is higher than the dependents. In countries such as Europe, there is the opposite problem: old age people are becoming increasingly more, and they are entitled to a pension that the workforce today is not able to generate. This trend is shown by the support ratio, figure 10 graphs its evolution according to the medium variant projection. Thus in developing countries, this demographic dividend could boost productivity and project some regions into economic flourishment. In 2018 more than 50% of the world population was 65 or older as of the result of increased longevity and decreased fertility, this number will only grow when in 2050 the over 65 will account to 1.5 billion and outnumber the aged between 15 and 24.(*table* 10)

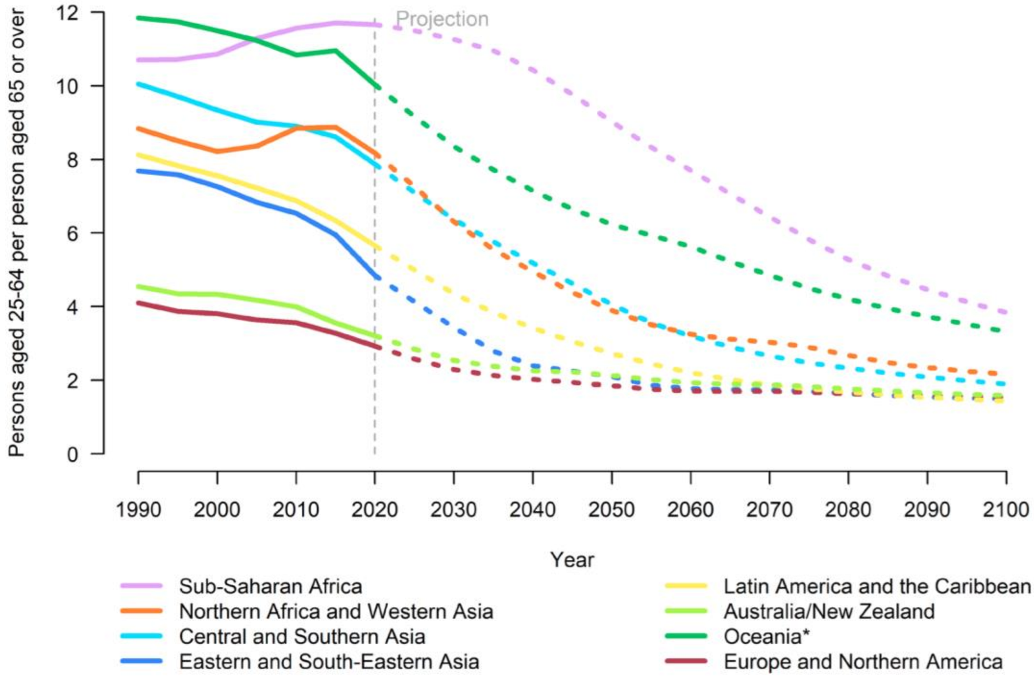


fig. 10 Past estimations and projection showing the decline in support ratio in SDG regions

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

Table 10 Percentage of population aged over 64 years

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

Region	**2019**	**2030**	**2050**	**2100**
World	**9,1**	**11,7**	**15,9**	**22,6**
Sub-Saharan Africa	3,0	3,3	4,8	13,0
Northern Africa and Western Asia	5,7	7,6	12,7	22,4
Central and Southern Asia	6,0	8,0	13,1	25,7
Eastern and South-Eastern Asia	11,2	15,8	23,7	30,4
Latin America and the Caribbean	8,7	12,0	19,0	31,3
Australia/New Zealand	15,9	19,5	22,9	28,6
Oceania	4,2	5,3	7,7	15,4
Europe and Northern America	18,0	22,1	26,1	29,3
Least developed countries	3,6	4,2	6,4	15,3
Land-locked Developing Countries (LLDC)	3,7	4,5	6,4	16,8
Small Island Developing States (SIDS)	8,7	11,9	16,1	23,7

Urbanization

Since the second industrial revolution, people began to flee from the countryside and converged around industrial sites, which demanded labor. These agglomerates evolved to modern cities and this migration, which started around 1850, became known as urbanization. Urbanization is a term under which lays a complex socio-economic transformation process strongly affecting every part of the population's lifestyle and culture (Montgomery and others, 2004) Based on economic theory regarding urbanization, the link between movement towards urban centers and economic growth of said centers was not in question and to validate even further this thesis, 80% of global GDP is generated in cities(Grübler and Fisk, 2013)But, as highlighted by Fay and Opal(1999) the Sub-Saharan region's urbanization process continued even while registering economic downfall in the thirty years between the 70s and the new millennium. While this economic theory is shaking, as they eventually all do, demographers (De Vries, 1990; Dyson, 2011)

Noted that the key drivers of population growth, fertility, and mortality rates, followed what had been observed in the past. Many explanations can be given to why in economic terms the numbers don't add up, but, what is essential for the purpose of this paper is to note that migration today is easier than in the past, and because of this, there is the need to fully understand that people will go where there is prosperity or at least hope that development and better living conditions will eventually follow. This forces us to weigh the risk of a rapid structural transition from rural to urban resulting in the rise of slums. Even if, as there has been over the last few decades, official authorities try to undertake the matter by building adequate homes and expanding the city borders, the newcomers are still neutralizing the effect of these policies. Living in sub-standard conditions means first of all that water access is an issue, and wastewater management a real threat. This is the main reason why, as demographic theory dictates, in the early stages of urbanization, growth in mortality rates will result from overcrowding in slums. Testified by 191 health and demographic surveys, conducted in countries of Latin

America, Asia and Africa during the past several years, infants and children residing in slums have an extremely higher under-five mortality rate and diarrhea illness incidence when compared to urban peers (Fink et al, 2014)

As for the projections regarding population, before analyzing the data, it is paramount to underline the forces that enhance urban growth. Greater than one birth/death ratio in urban areas resulting in a natural increase of urban population; the dynamics are the same of population increase in general with the consideration that usually in urban areas women have more chance of receiving an education and are more likely to have access to family planning services and therefore fertility isn't usually high. Despite this factor, life expectancy increases, lowering the denominator in the ratio, and hence, the fraction total can be higher than one. Net migration is another crucial driver to changes in the urban population. It can happen both from rural to urban areas or between urban areas with the result of, other than changing the population size, affecting the age distribution of said population. The trend involves young immigrants in their working years that tend to lower the age average of the receiving community while raising the one which they have left. Reclassification can be seen as a formality but is nonetheless essential because it expands the city's borders. Rural settlements can be incorporated and become a neighborhood of the growing city.

Trends

Projections show total urbanization percentages growing, from 2018's 55%, we will have by 2050 more than two-thirds, precisely 68%, of the total population residing in urban agglomerates. The most significant contribution to global urban population will be provided by mainly two regions, Africa and Asia. These regions have to this day rural population accounting respectively for 60% and 50% of their total inhabitants. Their effort in urbanizing will bring them to reach percentages of almost 60% for Africa and around 66% regarding Asia, which will be the driver for the global urban growth already mentioned. More specifically, at country level, the ones responsible for this growth are mainly three accounting for 2.5 billion new urban citizens by mid-century: China, Niger, and India.

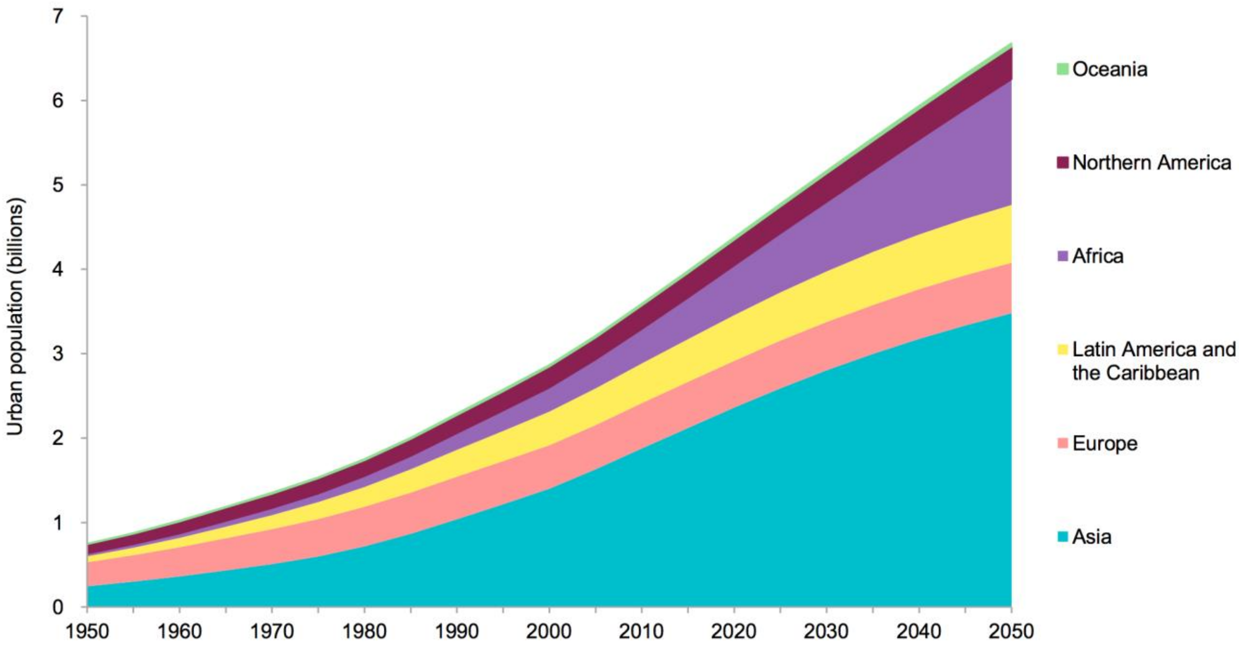


Fig. 11 Urban population of the world between 1950-2050

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

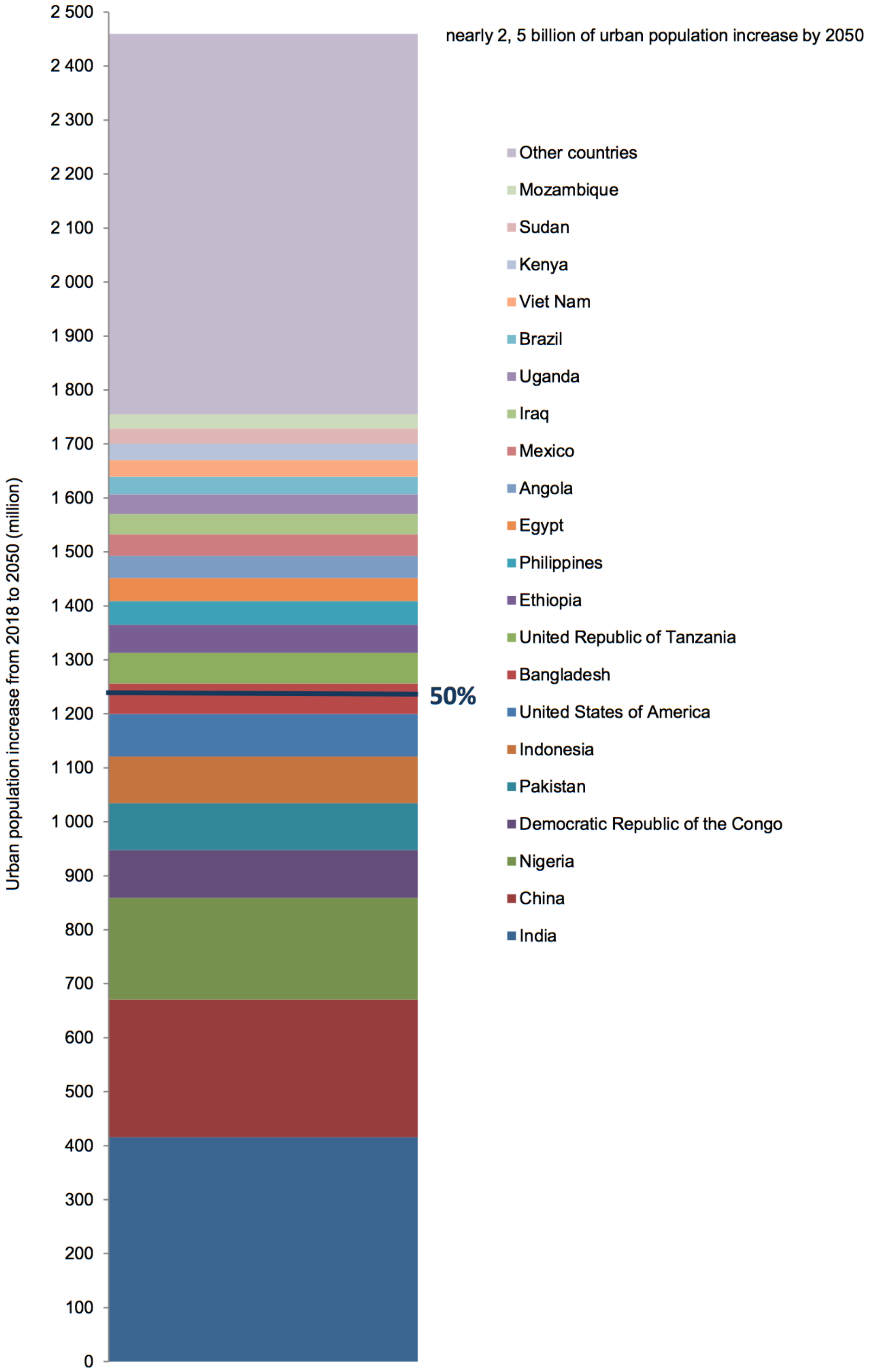


fig.12 country's marginal contribution to urban population growth between 2019 and 2050

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

On the opposite side of things we necessarily have a decline in rural inhabitants because China and India, today, account for 45% of the world's rural population, therefore, a shift in these nations changes the whole global scenario.

Urban settlements vary significantly in size from today's 33 megacities hosting over 10 million people to cities counting less than 300 thousand people. As shown in figure 13, more than two-thirds of the population live in small settlements, be they rural, 44.7%, or urban, 22.9%, with less than 300 thousand people.

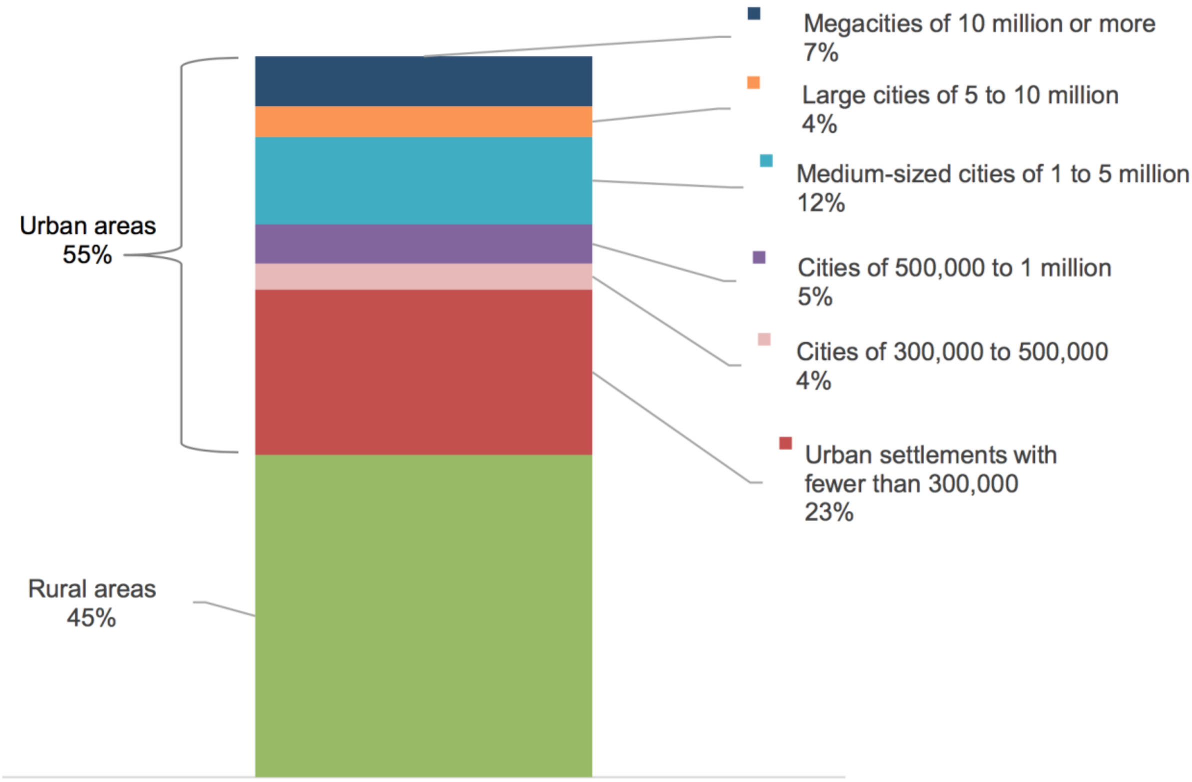


fig. 13 World population share in both areas (urban & rural) and in urban settlements by size in 2018

Data presents (table 11, fig. 14, and Fig. 15.) the tendency to move from rural settlements to large cities. The level of urbanization we have reached in developed countries is such that large cities tend to become more prominent while there is rarely an old settlement scaling up. In the developing world, on the other side, growth is so fast that new cities have to be built o substantially enlarged because of the speed and magnitude of this growth in developing regions. By 2030 Megacities and cities with more than 5 million people will see an increase of 13% and 17%

respectively while small urban settlement's percentages will start decreasing by more than 5%.

Table 11 World's population distribution by area and size in 1970,1990,2018,2030

Area of residence &	*Population (millions)*				*Percentage*			
Size class of urban settlement	1970	1990	2018	2030	1970	1990	2018	2030
Total	3.701	5.331	7.633	8.551	100,0	100,0	100,0	100,0
Urban area	1.354	2.290	4.220	5.167	36,6	43,0	55,3	60,4
10 million or more	55	153	529	752	1,5	2,9	6,9	8,8
5 million to 10 million	107	156	325	448	2,9	2,9	4,3	5,2
1 million to 5 million	244	467	926	1.183	6,6	8,8	12,1	13,8
500,000 to 1 million	131	208	415	494	3,5	3,9	5,4	5,8
300,000 to 500,000	87	159	275	320	2,3	3,0	3,6	3,7
Fewer than 300,000	730	1.147	1.750	1.971	19,7	21,5	22,9	23,1
Rural area	2.346	3.041	3.413	3.384	63,4	57,0	44,7	39,6

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

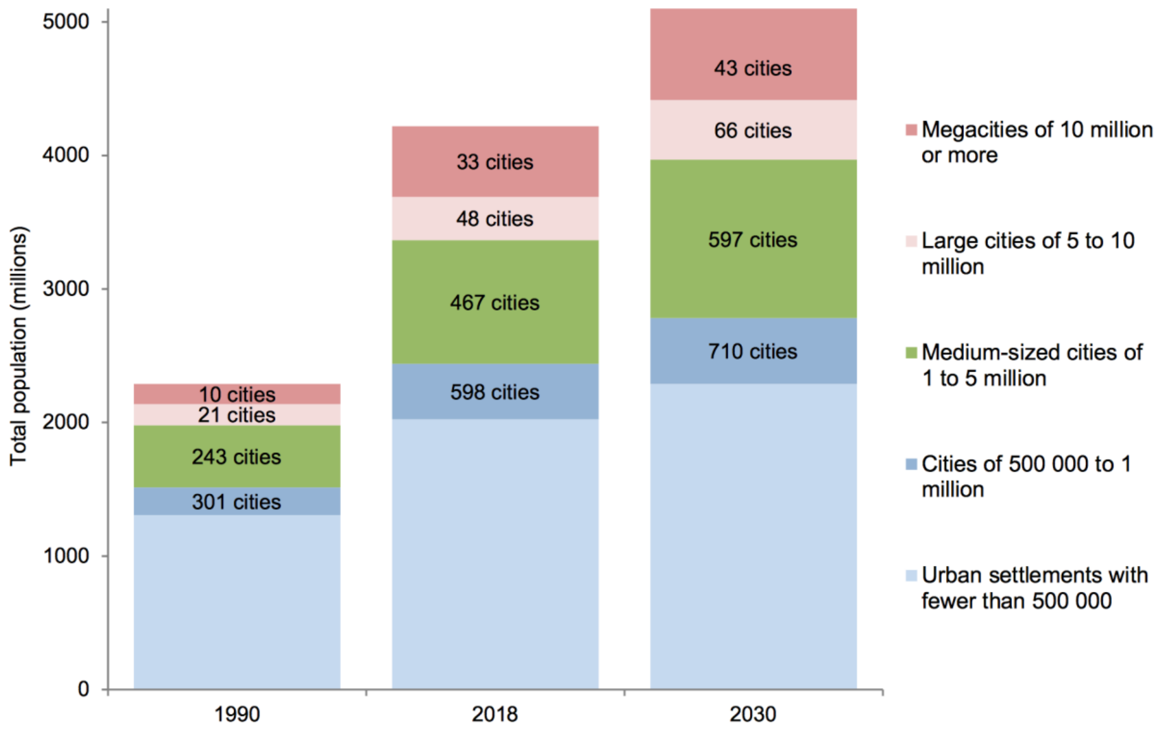


fig. 14 World cities

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

Table 11 Breakdown of World's population distribution by size of settlement in 1970,1990,2018,2030

Size class of urban settlement	***Population (millions)***				***Percentage***				***Number of urban agglomerations***			
	1970	1990	2018	2030	1970	1990	2018	2030	1970	1990	2018	2030
Africa Total urban population	83	200	548	824	100,0	100,0	100,0	100,0	…	…	…	…
10 million or more	—	—	47	91	—	—	8,5	11,0	—	—	3	5
5 million to 10 million	6	10	30	81	6,8	4,9	5,5	9,8	1	1	5	13
1 million to 5 million	10	46	122	167	11,9	22,9	22,2	20,3	7	24	55	81
500,000 to 1 million	8	20	50	77	9,8	10,2	9,1	9,3	12	29	71	111
300,000 to 500,000	7	17	34	45	7,9	8,3	6,2	5,4	17	43	87	117
Fewer than 300,000	53	107	266	364	63,6	53,6	48,5	44,2	…	…	…	…
Asia Total urban population	507	1.040	2.266	2.802	100,0	100,0	100,0	100,0	…	…	…	…
10 million or more	39	85	335	490	7,6	8,2	14,8	17,5	2	5	20	27
5 million to 10 million	32	98	201	246	6,3	9,5	8,9	8,8	5	14	28	34
1 million to 5 million	96	186	483	651	18,9	17,9	21,3	23,2	47	99	250	330
500,000 to 1 million	42	84	230	274	8,2	8,1	10,2	9,8	62	121	333	387
300,000 to 500,000	29	68	139	168	5,8	6,5	6,2	6,0	77	178	362	429
Fewer than 300,000	270	519	877	974	53,2	49,9	38,7	34,7	…	…	…	…

Europe Total urban population	415	505	553	573	100,0	100,0	100,0	100,0	…	…	…	…
10 million or more	—	—	23	35	—	—	4,2	6,1	—	—	2	3
5 million to 10 million	23	25	26	18	5,5	5,0	4,8	3,2	3	3	4	3
1 million to 5 million	62	85	87	94	14,9	16,8	15,8	16,4	33	46	52	55
500,000 to 1 million	47	53	58	62	11,3	10,5	10,5	10,8	67	78	88	94
300,000 to 500,000	33	44	43	43	8,0	8,8	7,8	7,6	87	116	114	115
Fewer than 300,000	250	298	315	321	60,3	59,0	56,9	56,0	…	…	…	…
Latin America & Carribean Total urban population	165	315	526	600	100,0	100,0	100,0	100,0	…	…	…	…
10 million or more	—	42	92	103	—	13,2	17,6	17,2	—	3	6	6
5 million to 10 million	32	16	18	31	19,2	4,9	3,4	5,1	4	2	3	5
1 million to 5 million	23	69	131	158	13,9	21,9	24,9	26,3	13	36	63	77
500,000 to 1 million	14	28	41	41	8,3	8,8	7,8	6,8	20	41	57	60
300,000 to 500,000	8	17	31	39	5,0	5,5	5,9	6,4	21	44	81	101
Fewer than 300,000	88	144	213	229	53,6	45,8	40,5	38,1	…	…	…	…
Northern America Total urban population	171	211	299	335	100,0	100,0	100,0	100,0	…	…	…	…
10 million or more	16	27	31	33	9,5	12,8	10,5	9,9	1	2	2	2
5 million to 10 million	15	7	50	61	9,1	3,5	16,6	18,2	2	1	8	9
1 million to 5 million	48	71	87	104	28,3	33,7	29,2	31,1	25	33	41	50
500,000 to 1 million	17	22	34	38	10,2	10,3	11,5	11,4	25	31	48	55
300,000 to 500,000	9	12	24	23	5,4	5,8	8,0	6,8	23	32	62	59
Fewer than 300,000	64	72	72	76	37,5	34,0	24,2	22,6	…	…	…	…
Oceania Total urban population	14	19	28	33	100,0	100,0	100,0	100,0	…	…	…	…
10 million or more	—	—	—	—	—	—	—	—	—	—	—	—
5 million to 10 million	—	—	—	11	—	—	—	34,4	—	—	—	2
1 million to 5 million	5	10	17	8	39,0	54,8	59,6	25,2	2	5	6	4
500,000 to 1 million	3	1	1	2	22,2	4,6	2,4	5,5	4	1	1	3
300,000 to 500,000	—	1	3	2	—	4,9	10,8	7,5	—	3	8	6
Fewer than 300,000	5	7	8	9	38,8	35,7	27,2	27,3	…	…	…	…

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

From a regional perspective, Oceania is the one that differs from the rest of the world. In fact, while in all other world regions the population lives in urban settlement of variable size, in Oceania there are basically only two categories of urban agglomerates, the medium-sized ranging between one and five million inhabitants and ones with less than five hundred thousand urban dwellers

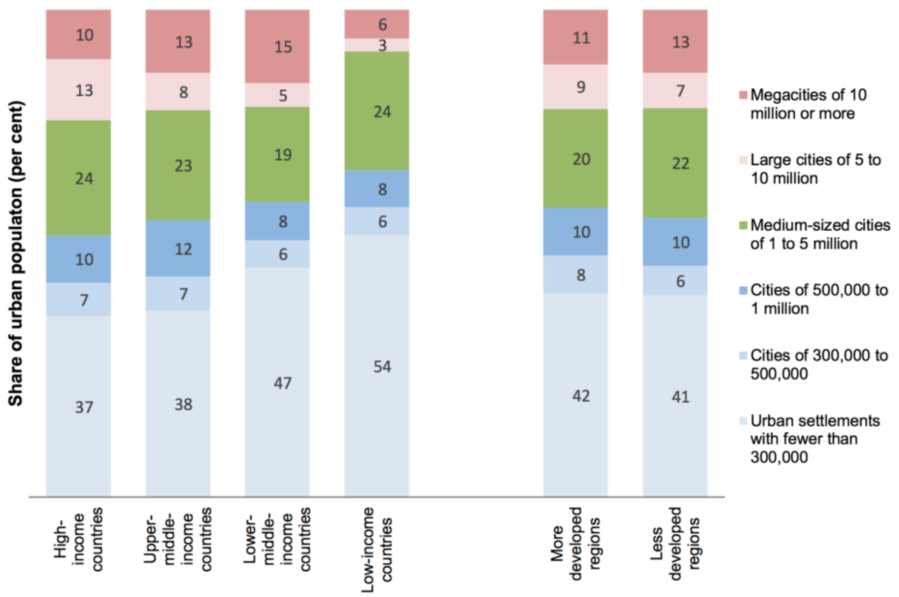


fig. 15 Urban dwellers divided in income groups and categorized by settlement size of residence

Data source: United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*.

In light of this, and furthermore considering the international community's New Urban Agenda urging countries to support smaller urban settlements, it appears clear that proper effective urbanization has not been figured out in every detail. The interconnections and subsequent complexity of megacities leave them exposed to impairing congestions and cause below average services for citizens. As discussed in the second section of these significant inefficiencies can be caused by overstressing the infrastructure built decades earlier, perhaps even kept alive more than planned with inadequate maintenance, which, past a specific limit, drain a massive amount of resources. In this matter Kennedy et al. in 2015

strongly argue with figures the inefficiencies in almost all areas of consumption for these agglomerates and Princeton's professor Rossi-Hansberg analyzes megacities and large urban agglomerates in the US and calculates the population percentage reduction to guarantee national average services in megacities and estimates the negligible effect it would have on the country’s economy as a whole. These observations are in line with the New Agenda, which encourages synergies between settlements for efficient use of resources and sustainable development.

Differences in city growth

Comparing historical pace of growth data in the periods between 1970 and 1990 with the following thirty years, 1990-2018, in all urban settlements urbanization rates fell by approximately 65%, 67% for cities with a population between 300,000 to a million and 64% for those with more than a million. Almost the same decrease in growth rate is expected in the 2018-2030 period regarding the larger centers while the small ones will preserve 76% of its growth rate suggesting that, as mentioned above, future growth will be absorbed by such agglomerates. Nonetheless, a few big cities go against this trend; African cities such as Kinshasa and Lagos, India's Bangalore and Delhi, the Pakistani city of Lahore and Bangladesh's Dhaka have staggering growth rates above 2.5% that could be sustained well after 2030.

For modeling accuracy, an analysis of freshwater resource location and trends will highlight where water stress, is today or will be in the future a significant concern for the urban population.

Centralized water management and growth

Buried infrastructures have two main problems; they are costly to built and very complicated to maintain or upgrade once in place. The major problem that the world is facing today in this regard is the fact that developed countries have a very old distribution network that requires extraordinary maintenance while fast-growing developing countries, on the other hand, need to get hold of enormous capital sources to finance their infrastructure.

The result is on one side that old networks leak astonishing amounts of water, of instance in Italy on average 41%, in regions such as Puglia the leakage amounts to 70%, of the water pumped into the distribution system gets lost in its ways to users. Maintenance of such infrastructures carries high costs, and many countries do not see the urgency of the situation and divert funds in more "tangible" efforts. The Delaware aqueduct, built during World War II, is the longest tunnel in the world and is used to supply half of New York City with drinking water. Special maintenance measures, for a total of approximately 2.1 billion USD have been approved to fix significant leakages in the tunnel and keep a regular water inflow in the city** [Inside New York City's $1 Billion Leaking Water Infrastructure Repair, June 22, 2018, Alyssa Danigelis]. On the opposite side distribution systems for developing countries are not built and people do not have access to safe water. In countries where growth happens fast around major urban centers such as the Democratic Republic of Congo, slums grow fast, and sanitary conditions are almost unbearable for the population.

Forecasting, as mentioned earlier, is crucial for sizing the distribution and collection network appropriately and given the high uncertainty caused by quick changes in modern times the total error equates to antieconomic oversizing of networks with costs that fall on taxpayers. As highlighted by L. Benefield 2002, the sources and the methodologies used to design these complex networks have changed over the years. Therefore, the reliability of forecasts made when so little information was available is very low. This situation forced engineers to hide even more behind safety coefficients which do not deal with the problem but instead delay it forward in time. Just twenty years ago, calculations for design purposes were made on a bedroom basis which today would appear odd and furthermore the data available was extremely low, forcing engineers to make very slim projections. Not having clear figures in mind results in a bigger problem which is not conveying any message regarding water consumption to the population. Between setting the bar too high or too low, to stay on the safe side it is necessary to oversize and therefore provide more; consumption patterns show that when more water is provided people will eventually waste more resulting in higher consumption which then increases future forecasts even more, and so the snowball starts rolling down the hill, quickly becoming unmanageable. Forecasts have to be adjusted, and projections grow through the roof.

Change of paradigm

To effectively integrate future population, a major paradigm shift is required both for newly built cities and for the old ones that must somehow be retrofitted. Current unsustainable practices must be transformed meeting emission targets and systematically reuse key resources such as water.

Institutions such as the National Science and Technology Council since the beginning of the century report potential savings accounting up to 70% in terms of building heating and cooling if appropriate features were considered during the design stage. Water as well is largely abused, and reuse is most probably the road forward.

The linear take-make-waste model feeding the urban metabolism has to transition to a more sustainable process involving reclaiming, reusing, and recycling. The linear approach in terms of water footprint not only comprises its direct use but also, and this could potentially be one order of magnitude higher than direct use, the virtual water used to deliver everything that is produced elsewhere and consumed in cities such as energy food and retail products**(Hoekstra and Chapagain, 2008).

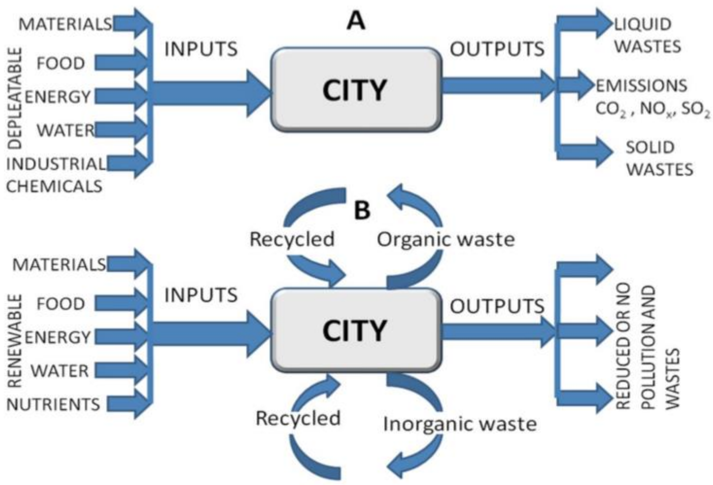


Fig. 16 Linear (A) and circular (B) urban metabolism systems (Novotny et al., 2010)

Energy-water nexus

Novotny in 2010 theorized and developed a relationship between the magnitude of the water demand and the cost of providing water in energetic terms (fig. 2). This relation can be segmented in three domains; an initial proportional decrease in energy consumption and GHG emission, associated with the reduction of excessive water use, followed by an inflection in the function due to an increase in energy to promote the use of alternative sources of water, this change in trend will steepen in the third segment as the reuse limit is approached utilizing energy-intensive techniques. What will theoretically happen is that the energy increase starting in the second segment and culminating in the third will ideally be sustained by renewable energies, therefore, limiting the CO_2 emissions.

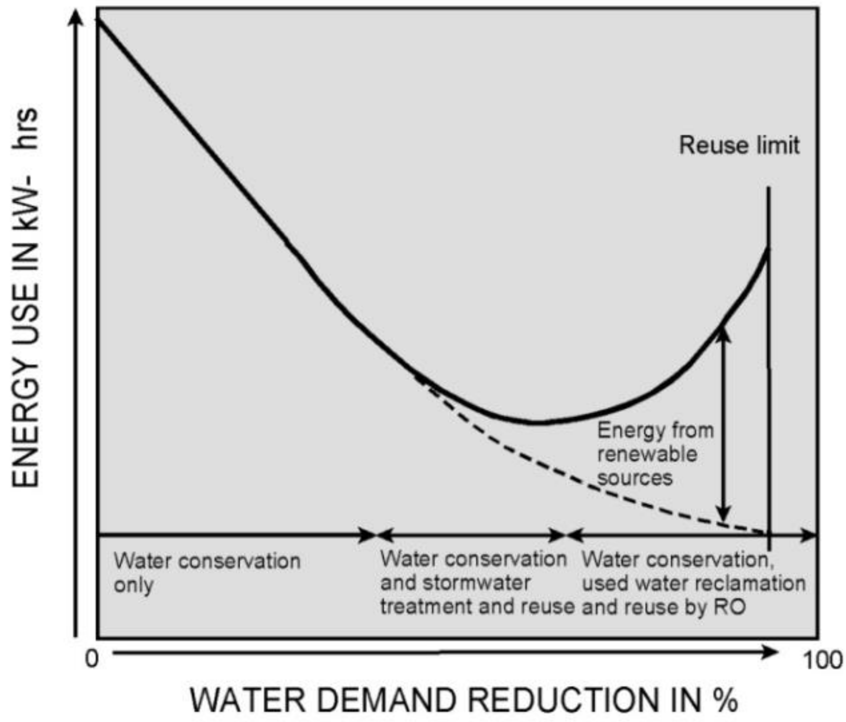


fig. 17 Three phases of the water-energy nexus (without energy recovery) Novotny 2012

As shown in the first section when discussing micro components like faucets or showerheads, or flushing devices using varying amount of water, a significant decrease in consumption can be achieved with little effort. In particularly arid territory common sense should suggest utilizing plants that do not require constant irrigation and maybe converting to xeriscapes. These savings will have the effect of lowering the demand for freshwater hence reducing energy consumptions. Inflection will start when water can be substituted for specific uses, or more water is added from distant sources such as deep seawater or groundwater. These sources contribute to saving freshwater resources at the expense of an energetic cost of pumping and treating water. Other sources are rainwater and stormwater harvesting, which can be utilized with small additional energy consumption.

The third segment, in which water savings are maximized at the expense of energy consumption and likely CO_2 emissions, is where the actual city design comes into play, the need is to understand which technologies best fit a particular environment. The divisions are infinite; a city could be grouped in new clusters and have satellite buildings intercepting sewer water and treating it partially and send it to buildings close by that would reuse the water for toilet flushing or gardening purposes. Decentralized treatment units could be installed in every building, and the semi-loop could be closing almost immediately.

Technology is the key to this planning process; in the next chapter, the aim will be to revise and understand decentralized greywater treatment units and evaluate their sustainability in terms of energy consumption.

Decentralized greywater treatment and reuse

Direct Reuse of Greywater

Direct reuse of greywater is a common practice. Greywater coming out of the bathroom has been used directly in garden irrigation works for centuries. Greywater is used directly in Australia, Syria, and South Africa for irrigation of gardens and landscaping, and in Israel for irrigation of fruit trees (Boyjoo et al., 2013). However, it is strongly recommended to treat greywater before use. The use of greywater directly for long-term irrigation results in the accumulation of salts, surfactants, oil, and grease in water. In this context, plant health and the soil structure is negatively impacted because of its progressive pollution. The use of greywater directly in reservoirs without staining leaves a stain on the toilet bowl. This encourages consumers to use copious amounts of toilet cleaners.

If greywater is used directly without any treatment, the storage time of greywater should be short. For example, the greywater coming out of the bathroom can be used directly to irrigate. With direct use, water is saved, and greywater storage problems are eliminated. The direct use is referred to as the Greywater Diversion Device (GDD) in countries such as Australia and America in the areas where droughts are frequent, and this system is implemented. This system has two applications. In the first application, it is ensured that the greywater coming out of the sink and washing machine is directly used in reservoirs without being connected to the wastewater line.

In the second application, greywater is used directly for garden irrigation with the help of a pump that transfers the water from the storage tank to the irrigation system.

Greywater Reuse After Purification

Depending on the characteristics of greywater treatment, physical, chemical, or biological treatment technologies are used to reach the desired standards. Precipitation and filtration processes are used as physical treatment technology. Filtration is usually used to provide pretreatment before biological or chemical treatment units because of its effluent quality which doesn't meet the standards [March et al., 2004; Wichmannand Otterpohl, 2009]. In the filtration process, some organic substances and pathogens can be removed using sand filter, coarse filter, or membrane filter as pretreatment. Physical purification technologies can not achieve nutrient removal. Therefore, in some studies, chemical treatment technologies are used for both particulate and nutrient removal. Chemical treatment technologies include electrocoagulation, photocatalytic oxidation, ion exchangers, and granular activated carbon (GAC). However, in order to prevent the use of chemicals, it is possible to perform greywater treatment with biological treatment technologies. Biological treatment, for greywater purification, uses technologies such as constructed wetland (CW), rotating biological contactor (RBC), sequencing batch reactor (SBR), membrane bioreactor (MBR) and other technologies. Usually, biological processes except for the membrane bioreactor, involve filtration or precipitation process as a pretreatment, and UV or chlorine disinfection as the final treatment in order to provide the greywater reuse standards discussed previously.

Water from the bathroom, shower, and bathroom sink is the most commonly used greywater in recycling technologies since they are less dirty than water from kitchen and dishwasher. The objective of this section is to review available technology and choose the one to implement in the model. The selection criteria will be based on compliance with reuse standards, energy consumption, maintenance, and occupation of physical space.

Constructed Wetland (CW)

There are two kinds of constructed wetland treatment systems, characterized by the main direction of the flow, horizontal and vertical.

Horizontal Flow Constructed Wetland

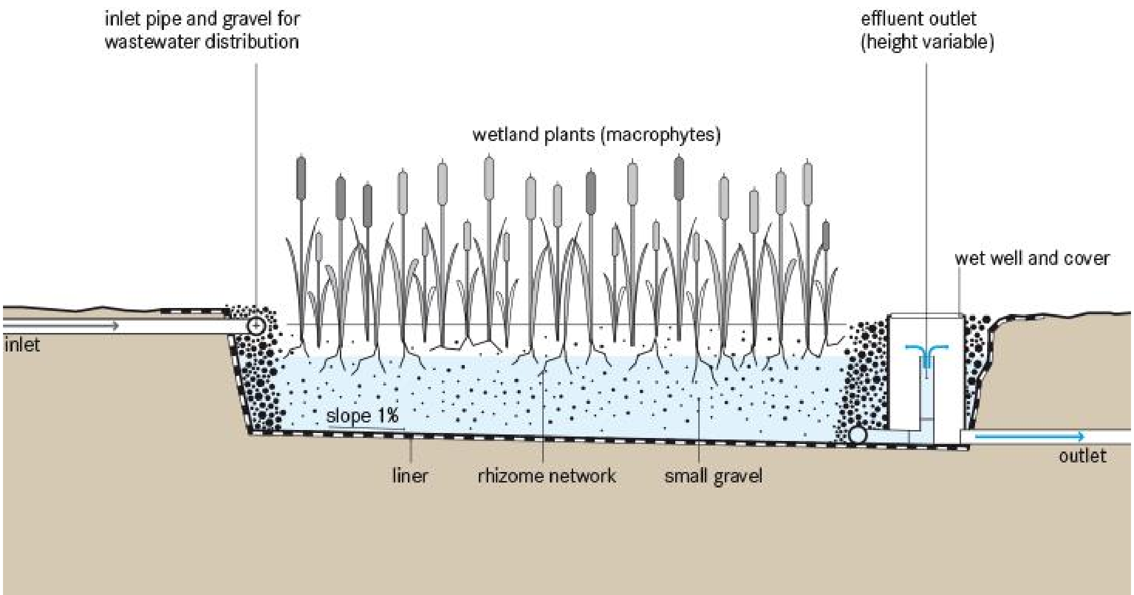


fig. 18 Schematics of HFCW [Tilley et al (2014)]

Horizontal flow constructed wetlands consist of an impervious bed filled with sand and gravel (Fig. 3). The pre-treated greywater flows through the filler and plant roots continuously and horizontally in the system. The plants provide the appropriate environmental conditions for the development of microorganisms and the transfer of oxygen to their roots. Table 7 provides the yield that said system obtains thanks to filtration and microbial decomposition under aerobic, anaerobic, and anoxic conditions. In order to prevent erosion in the system, the upper surface of the filter is horizontal, preferably at a 0.5-1% slope on the lower surface until the point where greywater enters the system. The grain size of the filler material must be such that it allows the continuous flow of greywater without clogging in the system. Coarse grains with greywater entering the system and leaving the system are responsible for ensuring that greywater is distributed evenly in the system. The characteristics of the superior layer of the system are determined by the organic matter content, texture, pH, and electrical conductivity of the soil. Plants and vegetation, in general, also have a central role in determining the type of effluent the system provides. For instance, the soil's pH affects the availability and retention of nutrients and heavy metals. The pH of the soil should vary between 6.5 and 8.5. For microbial activities, the electrical conductivity of the soil must be less than 4dS / m. The fact that the soil contains nutrients at low concentrations may limit the growth and development of microorganisms (Morel et al., 2006).

The hydraulic retention time in the horizontal flow artificial wetland system is between 3-7 days, the hydraulic load ratio is between 5-8 cm/day, and the organic load ratio is between 6-10 gr / m2 / day. In the presence of oxygen in the system, aerobic, anaerobic, and oxygen-free anoxic processes are observed in the absence of oxygen. Horizontal flow constructed wetlands are effective in removing organic matter and reducing suspended solids, their application is suited for places where space is not a major concern. The resulting effluent's characteristics are such that this natural solution can be used for disposing of greywater directly to surface waters or reused for irrigation purposes.

Vertical Flow Constructed Wetland

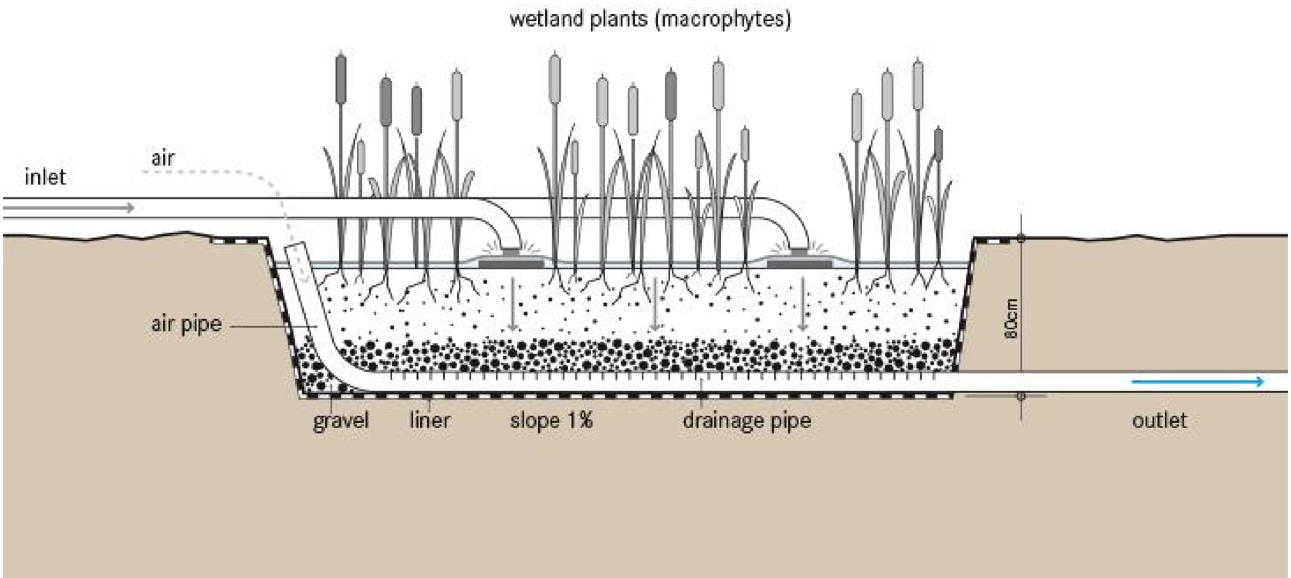


fig. 19 Schematics of VFCW [Tilley et al (2014)]

In vertical flow constructed wetland system, the pre-treated greywater is sent to the surface of the system intermittently with the help of pump (Fig. 19). The greywater flowing from the bed covered with the filler material is both filtered and it is contacted with the intense microorganism population on the surface of the system and on the plant roots. The design of vertical flow artificial wetlands depends on the hydraulic load and the organic load, and in this system, the hydraulic load ratio is 10-20 cm / day and the organic load ratio is between 10 and 20 g BOD / day. Typical filter depth in vertical flow artificial wetlands ranges from 0.8-1.2 m. The removal efficiencies obtained from this system are given in Table 7.

Table 12 Performance of Horizontal and Vertical flow Constructed Wetlands [Morel, 2006; Wojciech 2018]

Parameters	Removal efficacy	
	HF	VF
BOD	80,00%	86,00%
COD	75,00%	80,00%
TSS	87,50%	75,00%
TN	27,50%	55,00%
TP	37,50%	35,00%
Fecal Coliform	99,90%	99,90%

In VFCW system, BOD, COD, and pathogen removal efficiency is higher than in the horizontal flow case. However, SS removal efficiency is higher in the horizontal flow wetland system (Morel et al., 2006).

In general, for constructed wetlands, sizing and choices of plants and type of granulometry follow the rule of thumb because literature available provides conflicting results in terms of pathogen removal and effects of temperature or other factors. The synergetic nature of a series of reactions that occur in a seemingly random way must be investigated in the future. [Weber et Legge, 2008]

Rotating Biological Contractor (RBC)

Rotating Biological Contractors are used mostly in wastewater treatment plants after primary treatment but can also be designed for greywater recovery. These discs take up little space and consist of plastic units of certain thickness made of plastic. The shaft keeping the parallel discs together submerges them 35-40% of the way in the water that requires treatment. A motor connected to the shaft allows the discs to rotate continuously changing the part of the biofilm on the disc that comes into contact with the greywater. Organic compounds in greywater are kept in the biofilm formed on the disc by microorganisms, and a biological reaction occurs. The motor is kept running around the clock in order to avoid sludge buildup in the submerged disc. Microorganisms are provided oxygen coming in contact with air during the rotation of the disc (fig. 20). In greywater treatment, the deposition tank is conventionally placed after rotating biological discs, and the sedimentation tank is always followed by the disinfection unit which removes all pathogens but inevitably raises the cost in terms of chemicals and energy.

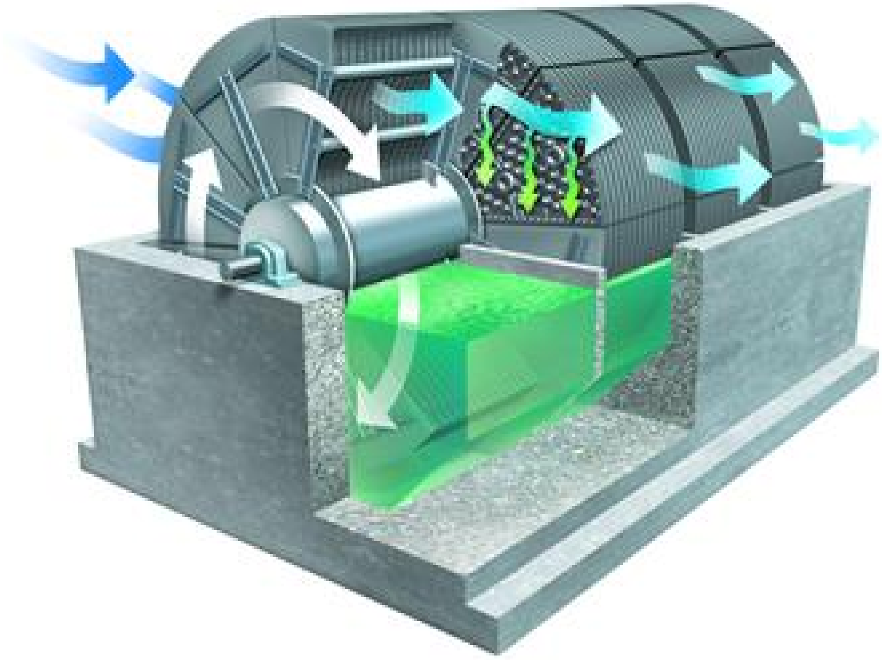


fig. 20 RBC working dynamics [Baban et al.,(2010)]

A selected study (Baban et al.,2010) investigated the reuse potential of greywater treated with rotary biological disc technology (Fig. 11). In this system, the greywater passing through the grill and storage tank is pumped into two rotating biological disks (RBC1 and RBC2) connected in parallel. The first of these rotating biological contractor (RBC1) has an area of 16 m2 and 36 disks, while the second rotary biological contractor (RBC2) is characterized by an area of 2.8 m2 and 20 discs. The input and output values of the greywater in this study are given in Table 13.

Table 13. Inlet and outlet characteristics of greywater treated with RBC

Parameters	GW avg. inlet	GW post treatment values		GW post treatment values		Removal efficacy [%]
		RBC1		RBC2		
pH	7,1	7,9	8,1	7,7	7,8	-
Temperature [C]	22	22	22	22	22	-
COD total [mg/L]	347	42	41	55	35,5	88%
COD dissolved [mg/L]	214	33	30	31	18	85%
BOD_5 [mg/L]	119	6,3	6,8	NA	NA	96%
total coliform [CTU/100mL]	$>10^6$	$5,6x10^4$ 0*	$2,8x10^4$ 0*	$6,3x10^4$ NA	$1,5x10^4$ NA	95%
turbidity [NTU]	103	6	13	17,1	4,4	91%
TSS [mg/L]	79	11	14	21	10	84%
TKN [mg/L]	8	2,3	1,5	3,5	2,6	71%
NH4-N [mg/L]	2,2	0,7	0,1	1,4	0,5	71%
NO3-N [mg/L]	NA	0,9	1,1	2,8	2,5	NA
P total	9,8	NA	NA	NA	NA	NA
FLOW [L/day]		400	150	86	43	-

*after UV disinfection

As an experimental result, Baban reports that after disinfection the effluent meets the standards and that from an operational point of view the costs associated with utilizing and maintaining this type of technology is similar to other greywater treatment technologies. Phosphorus removal with this technology can be considered to have the same removal capacity of activated sludge, which is less than 20% [Kim Sung-Tae, Biological Phosphorus and Nitrogen removal,1993]. Through polymer addition, removal rates increase between 52-91%, but in the case of greywater coming from less polluted sources such as the ones considered in this study, this operation will not be required. The disinfection process was carried out with UV lights which assured the pathogen removal, and as shown by the results, the CFU count drops to zero. A major drawback of this technology, like other less refined biofilm treatments, is biofilm detachment which inevitably obliges the water to undergo further filtration, hence increasing operational complexity. This specific technology is also limited in terms of flow rate, to be efficient, the disc has to be submerged in the right percentage, thus complicating its use where there is a significant variation of demand. Furthermore, because of this reason to operate, there is the need to have two settling tanks to homogenize the flow plus the reactor; the space requirement makes this solution generally unfeasible if not for specific situations. From a comparative study with other treatment technologies that will be analyzed next, this reactor used 1,2kW/ m^3 consumption point of view the reactor uses 1,2 kWh/ m^3 [Abdel-Kader, 2012].

Sequencing Batch Rectors (SBR)

The advantage of sequence batch reactors is that they solve the organic matter, nitrogen and phosphorus problems of greywater in the same tank. The SBR quickly regulates the inlet water characteristics making it one of the preferred technologies for the in-situ removal of nutrients, especially in greywater treatment. The sequencing batch reactor treatment system is based on the filling-discharge principle in which the filling, venting, settling, discharging, and resting phases occur sequentially in the same tank. The SBR consists of several tanks running parallel to each other depending on the sizing requirements. In the filling phase, the greywater is supplied to the reactor, and the content is mixed, this usually occupies 25% of total HRT. In this initial step, aeration will cycle on and off to maintain the proper level of dissolved oxygen necessary for the next stage. The reaction phase takes up approximately 35% of HRT, the air pump and the diffuser ventilate the inlet in order to initiate the microbial and chemical digesting actions. Mixing and ventilation are interrupted for sedimentation, 20% of HRT, after which the best quality water can be drawn from the surface (15% of HRT). The remaining part, sludge, and water is kept idle for 5% of HRT to allow part of the sludge to be waste and bring back the tank to desired conditions of mixed liquor suspended solids to start another cycle. (Fig. 21)

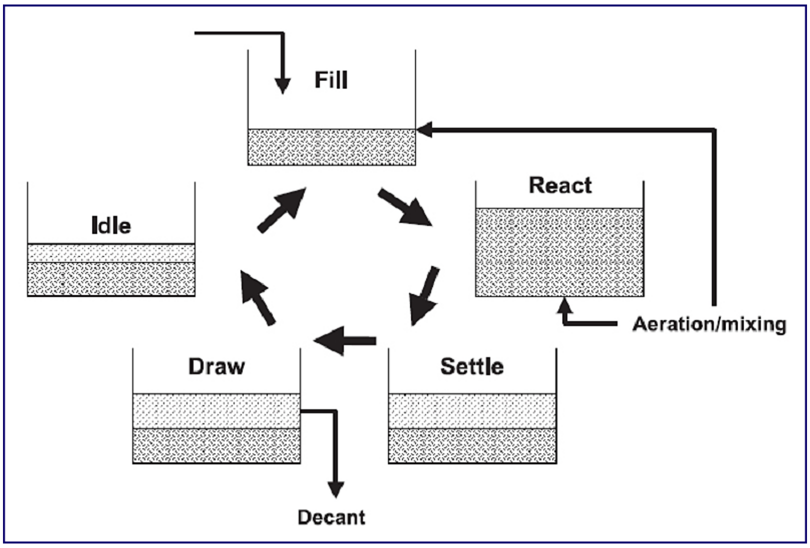


Fig. 21 Sequencing Batch Reactor [Mahavi, 2008]

Carbonaceous constituents such as BOD, COD and TSS can be removed through sequencing batch reactor with high efficiency, up to 90% (Dohare and Kawale, 2014; Obaja et al., 2005) with values as high as 95% (Mahavi et al., 2004) for COD removal which as discussed before is one of the major problems in water pollution. In fact, its ability to remove organic carbon makes SBR-based treatment very resistant in facing loading variability, which in turn guarantees a reliably stable process. In the fields of TSS and VSS removal efficacy, as reported by Fernandes et al. (2013) the value is assessed respectively at 70% and 80%. This approach was tested in the laboratory resulting in the promising numbers in table 14. In a comparison study, under the same conditions as the RBC it registered an ECI m^3 of 3.6kWh/ m^3.

Table 14 Ismail et al. (2014) and Mohd Razman Salim and Salmiati Salmiati, Phosphorus removal wet market (2016)

Parameters	Influent	Effluent	Removal efficacy
temp [C]	28,03	28,56	-
pH	6,63	6,2	-
BOD_5 [mg/L]	128,6	4,93	96%
COD [mg/L]	160,66	17,66	89%
TSS [mg/L]	128,13	6,72	95%
TN [mg/L]	26,66	0,99	96%
TP [mg/L]	NA	NA	67%

Membrane Bioreactors (MBR)

Membrane bioreactors are defined as advanced activated sludge methods. Membrane bioreactor treatment system consists of membrane ultrafilter and aerobic biological treatment reactor. After biological treatment in the system, solid / liquid phase separation is carried out using ultrafiltration (UF) or microfiltration (MF) membranes instead of settling tank (Fig. 22 & 23).

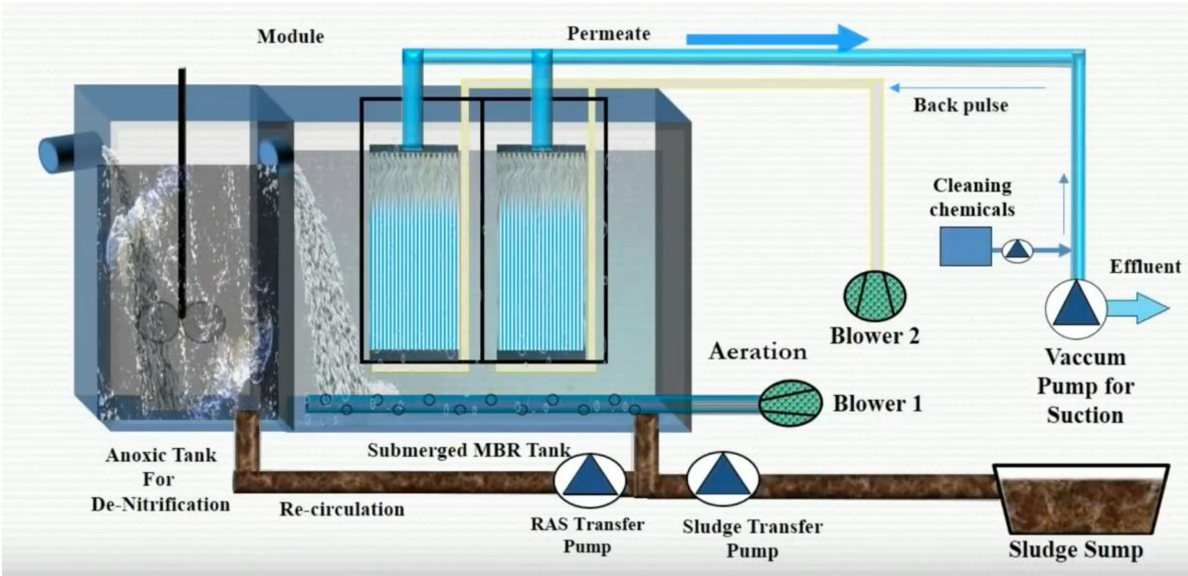


Fig.

fig. 22 Submerged MBR (open source)

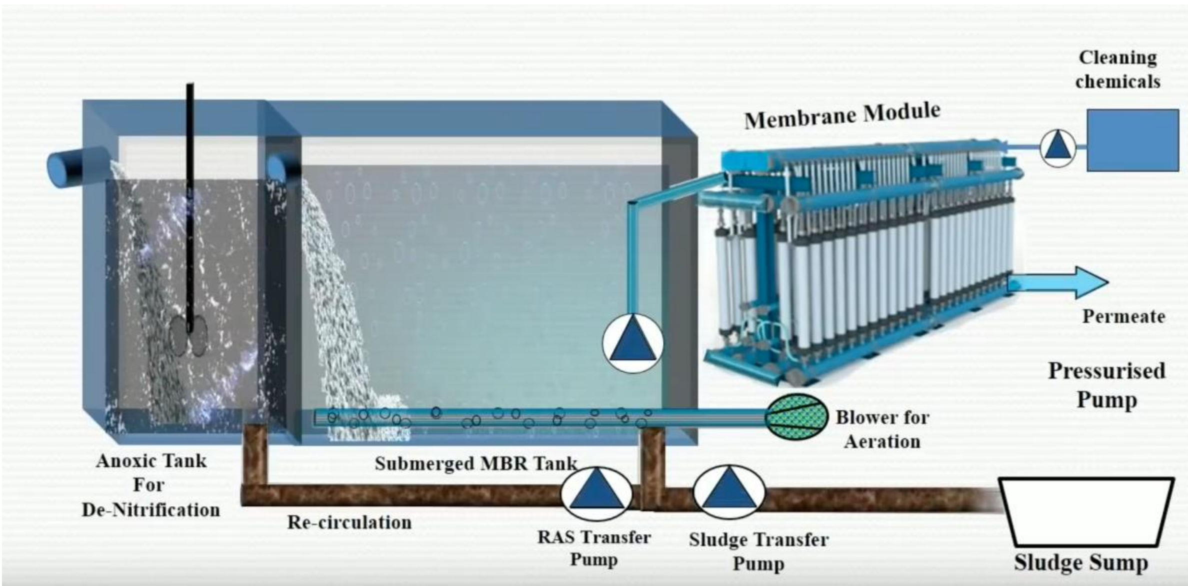


Fig.

fig. 23 External MBR (open source)

The operating principle of the system is briefly as follows, it is roughly an upgrade of classic activated sludge treatment: greywater preliminarily undergoes an anoxic phase to remove nitrogen, then it is sent in a tank where it is biologically treated thanks to the influx of air. The subsequent passage under pressure in the membrane (0.10 - 0.15 bar) allows the removal almost completely of particles, bacteria and viruses by filtration through the membrane filters. The quality of water obtained from membrane bioreactor treatment system is much higher than other systems.

Santasmanas et al. (2013), in their experiment tested this technology on greywater adding a chlorine disinfection unit as a final treatment. The characteristics of the greywater entering the system and the characteristics of the membrane effluent are shown respectively in Table 15 and 16.

table 15: Inlet greywater characteristics [Santasmanas et al. (2013)]

Parameters	number of samples	greywater		
		minimum	average	maximum
pH	50	7,2	7,7	8,3
Conductivity [miS/cm]	50	910	1267	1652
Turbidity [NTU]	50	50	68	158
BOD_5 [mg/L]	50	50	138	258
COD [mg/L]	50	153	302	461
Surfactants [mg/L]	25	0,1	7,1	20
E-coli [CFU/100mL]	25	80	$3{,}3 \times 10^4$	$4{,}4 \times 10^4$
Nematode egg [egg/10L]	25	<1	<1	<1
P total [mg/L]	25	0,8	3	15
N total [mg/L]	25	11	23	36

Table 16: Outlet characteristics before disinfection [Santasmanas et al. (2013)]

Parameters	number of samples	greywater			Removal efficiencies [%]
		minimum	average	maximum	
pH	50	7,5	7,9	8,3	-
Conductivity [μS/cm]	50	931	1244	1633	-
Turbidity [NTU]	50	0,2	1,2	4,3	98
BOD_5 [mg/L]	50	1	6	16	95
COD [mg/L]	50	5	29	74	90
Surfactants [mg/L]	25	0,06	0,1	0,6	98
E-coli [CFU/100mL]	25	<5[a]	<5[a]	100	99.9%(4log)
Nematode egg [egg/10L]	25	<1	<1	<1	-
P total [mg/L]	25	2	3	8	-
N total [mg/L]	25	14	22	30	-

a= dectection limit

The operating principle of the system is briefly as follows, it is roughly an upgrade of classic activated sludge treatment: greywater preliminarily undergoes an anoxic phase to remove nitrogen, then it is sent in a tank where it is biologically treated thanks to the influx of air. The subsequent passage under pressure in the membrane (0.10 - 0.15 bar) allows the almost complete removal of particles, from bacteria to viruses by filtration through the membrane filters. The quality of water obtained from a membrane bioreactor treatment system is much higher than other systems.

Santasmanas et al. (2013), in their experiment, tested this technology on greywater, adding a chlorine disinfection unit as a final treatment. The characteristics of the greywater entering the system and the characteristics of the membrane effluent are shown respectively in Tables 10 and 11.

These results confirmed the findings of Atasoy et al. (2007) who experimented obtaining similar results in Turkey operating a 600L MBR, their average removal efficiencies for COD, total nitrogen and suspended solids were respectively 95%, 92%, and 99%. While even more recent studies have confirmed the high removal of such parameters(Shin et al., 2014; Zhang et a., 2014), phosphorus removal, as witnessed by Johir et al. in 2015, removed 53% of this nutrient and observed that in order for bacteria to uptake phosphorus, there is the necessity of alternating between anoxic and aerobic conditions. The University of Cape Town-MBR configuration proves highly effective in the removal of nutrients, both N and P by having separated anaerobic, anoxic and aerobic tanks it allows almost total denitrification and phosphorus uptake by bacteria of around 88% (Monclus et al., 2010; Smith et al., 2012; Sun et al., 2013) . This is partially out of our scope because of the low concentrations of phosphorus in greywater. It acquires more significance in the scope of sewer water treatment plants that later discharge in natural water bodies for reasons linked to the risk of eutrophication discussed in section two.

Regarding pathogen removal, while many other biological treatment units have to operate with a disinfection unit connected between the reaction tank and the storage tank, as reported by Shang et al. [2005], MBR performs outstanding removal of E. coli and fecal coliforms. Drinking water standards in the field of fecal streptococci, according to Ueda and Horan [2000] are met.

Energetic consumption of MBR is incredibly variable depending for the most part by flow rate but also on the type of components utilized. In literature (Jabornig, 2014; Fountoulakiset al.,2016) values range from 3 to 6 kWh/ m^3 for small scale applications, daily treated water 0,2-0,6 m^3. for higher flows, 1-1,5 m^3/day energy consumption varies from 1,4 to 3kW/ m^3. Atanasova et al., (2017) plot the economies of scale in MBR consumption with efficiency rapidly rising to 0,5kWh/ m^3 for flow rates that exceed 15 m^3/day. Through independent research, a manufacturer has provided the consumption values of his package plant consuming overall 0,22kWh/ m^3 from 1 m^3 of daily flow rate. The value appeared low even when asking other researchers, but the treatment units using these technologies have been applied and are commercially available; therefore, the number was accepted in the study.

System design

As described in previous sections, the amount of greywater produced per household covers the potential reuse supply, and therefore, it is not necessary to purify the whole greywater. For this reason, it is much more advantageous to take the less polluted greywater (from the shower, from the bathroom sink, from the tub) to the system. Conventional greywater systems in buildings follow a simple cycle in order to optimize space and have advantages from a bigger scale.

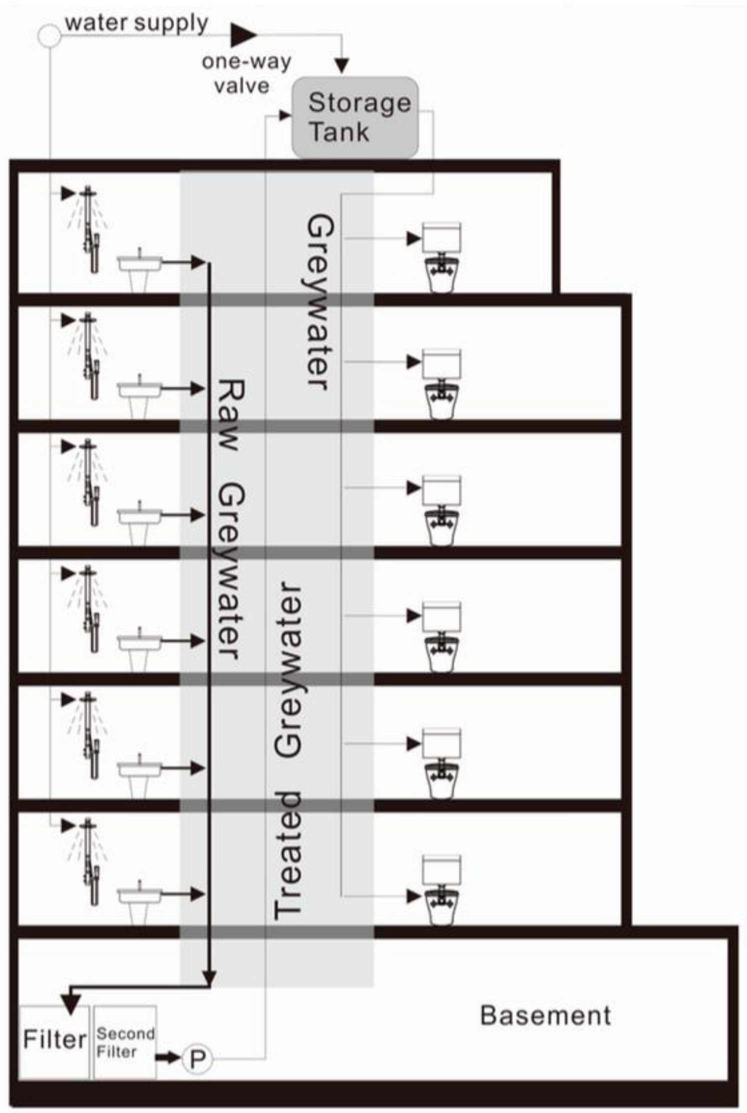


fig. 24 Conventional greywater system

The system can have an accumulation tank in the basement where the treatment unit resides or under the roof. In the first case, the pump is actioned whenever the system requires water; in the latter, gravity provides water with adequate pressure to fulfill its duty. In the system, the mains and lines abducting from the greywater tank must not be connected in any way. By making a different color of the pipeline through which the domestic water passes, it is ensured that the difference between the water lines is easily understood. Ventilation lines should be used to prevent odors in the warehouses used in the greywater recovery system. For smooth application of water recycling, pre filers that stop hair and other solids from coming in contact with the membrane is of vital importance. The pipes that come into contact with untreated greywater should be designed to allow the hair to settle in a place where it can be easily removed. Pumps, filters, and other mechanical equipment must be easily accessible and cleanable for repair and maintenance.

Selected technology and specifics

Table 17 summarizes all the reviewed technologies with their treatment efficiency for specific pollutants together with the energetic consumption required to deliver such performances and demonstrates the treatment of the virtual greywater as hypothesized in the first section. Values highlighted in green made it past the Italian reuse standards and therefore are still candidates the model discussed in the final chapter.

Table 17 treatment summary

	Removal efficacy					
	BOD_5	COD	TSS	TN	TP	kWh/ m^3
CW horizontal flow	80%	75%	87,50%	27,50%	37,50%	-
CW vertical flow	86%	80%	75%	55%	35%	-
RBC	96%	88%	92%	71%	20%	1,2
SBR	96%	89%	95%	96%	67%	3,6
MBR	95%	90%	99%	92%	53%	0,22
	Performance Assessment					e-coli
CW horizontal flow	27,1	89,0	14,9	8,0	0,7	1,1
CW vertical flow	19,0	71,2	29,8	5,0	0,8	1,1
RBC	5,4	42,7	9,5	3,2	1,0	1,1
SBR	5,4	39,2	6,0	0,4	0,4	1,1
MBR	6,8	35,6	1,2	0,9	0,6	1,1

The two naturalistic approaches fail to make the cut, not only because of the problems in treating completely BOD_5, but most importantly because of total suspended solids which are not completely removed. Evidence in literature in all the cases cited and reviewed in this section that had real life application, while discussing the various technologies report a low level of acceptance by end-users. The distinctive turbidity, even if harmless, gives the constant impression of a nonhygienic ambient people, especially living in cities, are not keen on seeing turbid toilet water. All the other technologies mentioned apparently passed the test, but, if we net the result from post treatment disinfection, the only acceptable technology is MBR. Furthermore, the only technology that as to this day is accepted, even in touristic locations, and fits the safety guidelines without UV or other forms of disinfection is greywater reuse after MBR treatment. Hence after having reviewed the available treatment technologies, due to effluent quality, to unrivaled energy consumption, ease of maintenance and low space requirements the decision was to utilize in the model an MBR system, specifically the one provided by Idro Group. IdroCel is a modular package treatment unit ranging from 1 to 9 m^3/day of greywater treated.

Table 18 retail prices

IdroCel greywater treatment unit	
size [m^3]	Price [$]
1	8000
2	11200
3	14200
6	19900
9	26200
membrane (per m^3/day)	1000

Regarding the design specifics, these units can be installed in basements or underground with conventional internal dynamics. The units come with two tanks respectively for storage before and after the treatment. The retail prices are presented in table 18. The great advantage of this technology is the simplicity of maintenance which only involves membrane substitution once a year; each membrane can treat up to 3 m^3/day of water. The pumps recommended by the manufacturer are monophase pumps that require 0,6kWh/ m^3 for the smaller modular units and rise in efficiency up to less than 0,4kWh/ m^3 for bigger treatment units that need a pump with higher flowrates and more power, resulting in better unit consumptions. Prevalence values are around 40 meters for said flowrates. These values are such in stationary use although, because of the intermitting nature of the reuse units in households the pumps, which are responsible for the most significant share of energy consumption in the decentralized scheme, the adequate consumption can be approximated to 1kWh/ m^3.

After having presented a review of decentralized treatment technology, completing the broader review conducted in previous chapters, it is now time to bring all the gathered information together in the model and discuss its results.

MODEL

Research question:
is the current centralized water cycle sustainable in the future, or is a shift in paradigm required?

As a premise to this model, it is necessary to clarify its aim. This model does not aim at representing precisely every aspect of consumption on a global scale in the year 2015, which is the beginning of the modeling period. The intent is to provide a future outlook of what the global urban water cycle could look like if today's approach in managing urban water in developed countries were widespread around the world. The model's projection is built on the assumption that living conditions around the world will tend to reach at least a minimum standard, therefore, implying an average minimum quantity of water consumption. Although domestic consumption represents a minor percentage in the grand scheme of things, when talking about the source of life on earth, no stone can be left unturned. Water is a basic need, and it is a limited resource, in order to grant access to all, its management has to change. Hence decentralized treatment is viewed as a possible solution, and the model will try giving a sense of its magnitude and feasibility.

This model has been developed as a tool through which both people who are active members of a community and country policymakers, can grasp the effects of habits and the importance of correct resource management and forecasting. The model is highly flexible and customizable based on user’s needs. After having analyzed the model’s structure an example of the output will be presented.

Structure

The model is divided into four parts; they each answer to one aspect of the main question:

- Worldwide, is water-saving the urban priority?
- From a resource perspective, what is the impact of the man-made hydrologic cycle dynamics?
- Is partial decentralized treatment a financially viable solution to reduce domestic water use?
- What are the likely effects of a partial hybridization of the centralized water cycle on a global scale in the foreseeable future?

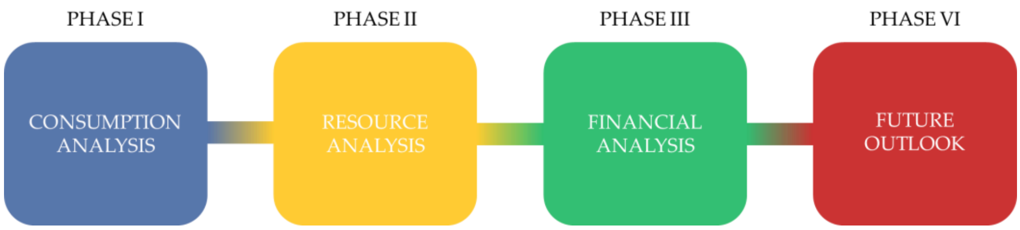


Fig 25 General flow diagram

The model performs analysis on a global scale by computing resource usage and the value it carries. Starting from the consumption of a single facet, it builds a projection to reflect consumption in selected countries. This number is compared to an actual consumption figure calculated based on available data. The estimated consumption value, hence set as a minimum standard in urban settings, will serve as a comparison unit, across the field of variables, undergoing treatment both in a conventional centralized cycle and in a hybrid, cycle implemented at full scale. Later a financial evaluation will determine whether or not the implementation of said cycle is a viable option. The concluding calculations will project consumptions and management options in the future and test them against existing natural resources. The model builds on the urban population data provided mostly by the United Nations and World Bank databases. It considers all the world's regions and subregions and, out of these, the countries with the most urban dwellers. These are considered representative of the urban state of development in said areas.

FIRST PHASE – consumption analysis

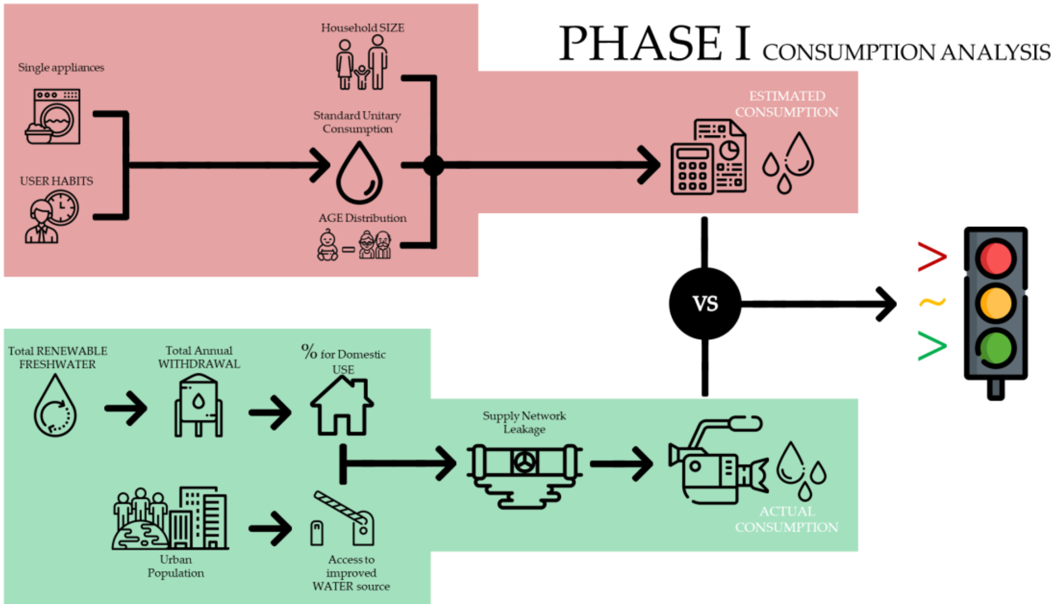


Fig. 26 Schematics of phase 1

The first aspect to cover is modeling the single consumption with the data and the assumptions described in the first chapter.

Initially, to compute the two consumption figures from which the model unrolls, for each nation, the following data were considered:

- P_u = Urban population;
- $W_{withdrawal}$ = Total annual water withdrawal;
- $\%_{Dom\ Demand}$ = Percentages linked to domestic consumption (Domestic Demand);
- $\%_{Access}$ = Urban population with access to improved water quality;
- $S_{Leakage}$ = Supply network leakage;
- $\%_{HH_n}$ = Household size data (number of members: 1,2,3,4,5+);
- f_{HH_n} = Household correction factor
- $\%_{Age_m}$ = Age distribution of the urban population (1 = 0-14 yo, 2 = 15-64, 3 = over 65);
- f_{Age_m}= Age correction factor
- U_{WC} = Unit consumption.

The computation considers the 2015 urban population of each country in order to have reliable correlated data and avoiding a systematic error. The percentage of the population with access to improved water sources served as an initial filter to select the actual consumer base. Household size data splits the resulting figure in agglomerates of four different sized families. Data is available for single households, for groups of two and three people, from four to five and for more than six.

For the households sized as an interval, the central figure was selected, two-point-five and four-point-five. In the first section, when discussing factors influencing agglomerate consumption, data was provided with unitary increases in household size, this drawback was resolved with a linear interpolation of the two values. Also, a household average size from the same dataset was used to determine the exact size of the households with more than six dwellers for correct calculations. Regarding the age of the household, once the distribution is defined for the urban population of the specific nation, a weighted average of the coefficients, introduced in the first section, allowed to model consumption variation effectively. Once this initial assembly of parts was concluded, the unitary daily consumption, which was assumed in the first chapter of the paper, was plugged in and provided the daily consumption of our virtual population (Estimated water daily demand, E_{WdD}).

$$E_{WdD} = U_{WC} * P_u * \%_{Access} * \sum_{n=1}^{5} (\%_{HH_n} * \left(1 + f_{HH_n}\right) * \sum_{m=1}^{3} \left(\%_{Age_m} * f_{Age_m}\right)$$

To compare this result, after extensive research, rather than taking a value in literature, the decision was to compute an actual for reliable raw data. Of the figures considered, some were not available for the most recent years; the total freshwater withdrawal and the percentage destined for domestic use imposed the year during which the estimation had to be calculated. To effectively reverse engineer the data to per capita consumption (Actual water daily demand, A_{WdD}), once the period and the withdrawal amount was set, together with population and access to improved water sources, the supply network leakages filtered the calculation.

$$A_{WdD} = \frac{W_{Withdrawal} * \%_{Dom\,Demand} * (1 - S_{Leakage})}{P_u * \%_{Access}}$$

Once the two consumptions are expressed in daily liters per capita, they can be compared. The comparison will position the country as to their state of urbanization in terms of water consumption. Traffic light code will answer the question faced in this first modeling phase.

Hence three scenarios are possible; we will refer to the GREEN scenario when estimated consumption is lower than the actual consumption

and to the RED scenario in the opposite case, respectively equal to YES and NO. When the two values differ by less than 10%, YELLOW scenario, a conscious approach to water consumption could be the cause or it could be a RED scenario country which is transitioning to higher consumptions so we can consider it a MAYBE.

Usually, in the RED scenario countries the priority is mostly getting water to people because of limited resources available, lack of investment in infrastructure, or both. When the model shows the country's name in red, chances are that the reuse scheme, today, has no grounds on which to work because these countries are still developing. The government provides access to electricity and water to increase the quality of life and push development. For example, in Ethiopia, the cost associated with generating electric power is fifty percent higher than the actual price charged to end-users (Richter,2015).

GREEN scenarios are mostly located in developed countries where water is given almost for granted. Here consumption levels can be way above the modeled figures. At this point, we should remember that this study only deals with indoor domestic waters and therefore, irrigation and activities such as car washing are not considered. These were not considered both for very high variability, limited data availability and because the water being used, for said purposes, does not have to comply with drinking water standards making it a candidate for reuse. Therefore, this study sets out to determine water reuse in the worst-case scenario of exclusively indoor use. If the data demonstrate its feasibility, then the yield in the real-life applications can only be higher.

SECOND PHASE – resource analysis

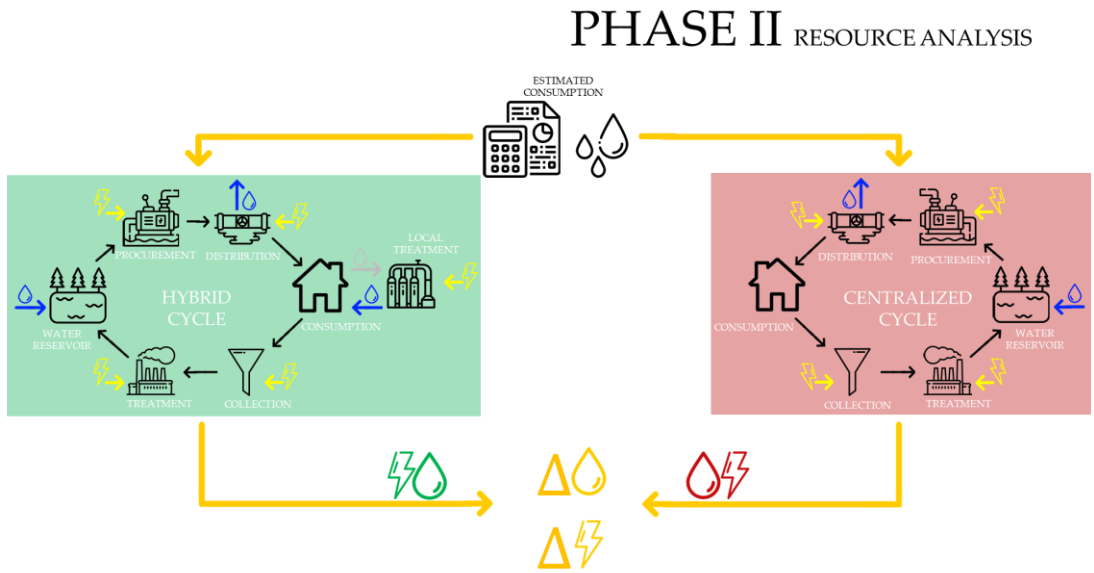


Fig. 27 Schematics of phase 2

The water consumed by the urban dwellers daily is hence funneled through two cycles that run in parallel; a centralized cycle and a hybrid cycle. Considering the estimated consumption figure allows for cross-country comparisons while keeping, as mentioned earlier, the worst-case scenario in place. Energetic consumptions are calculated as well as the total water demand of each cycle to deliver the appropriate demand to end-users. For each country in the study, detailed research has been carried out to determine the average energetic consumption rates of the four stages of the centralized cycle: raw water treatment, distribution, collection, and final wastewater treatment. An average, using the county's population as a weight, was computed for the countries with available data. This value was assumed as a world average and applied to those with unavailable data.

By comparing the total water processed by each cycle and the energetic expenditure to deliver said resource, both the savings in terms of water and the correlated energy delta was calculated. Computing the ratio between the difference in energy expenditures of the two cycles for the same amount delivered to the final users and the saved water provides the energetic cost to save water in kWh/ m3. This ratio is increasingly relevant for a country, the more difficulties it encounters in accessing and treating raw water and delivering it to final users. This figure alone serves as the first sign on whether adopting a hybrid cycle can be of value to the country's policymakers. In this second phase of the model we well and truly grasp the sense and the impact of decentralized treatment: having a “local” infrastructure which allows us to depend less on the central facilities reducing the system’s fragility. Infrastructural deterioration impacts the total water demand in a non-linear fashion hence elevating the value that the hybrid cycle can delivered (fig 28). This relation shows on one side the potential of decentralized solutions and on the other the inevitable reliance on the centralized water network, MBR or any technology can’t save water which doesn’t arrive.

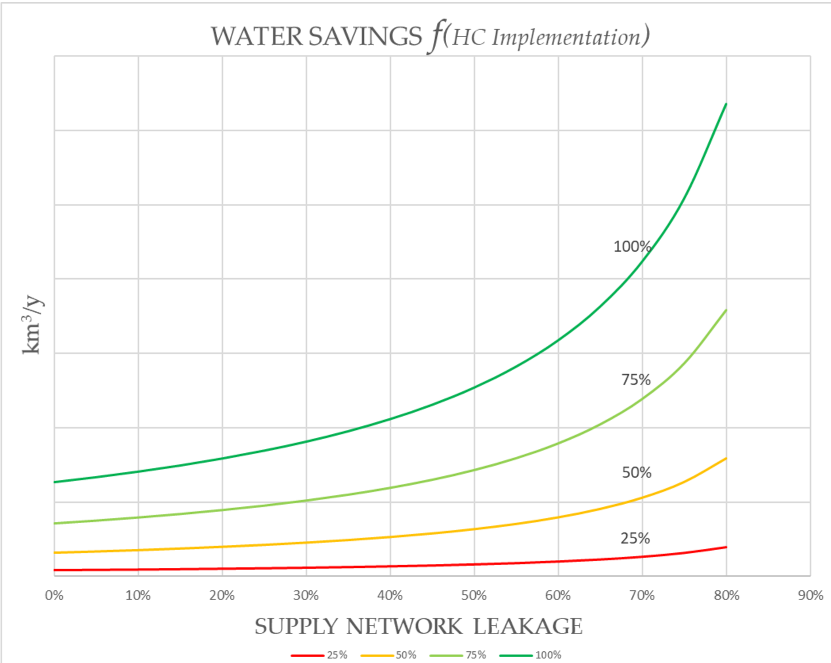


Fig. 28 HC water saving potential: the four curves indicate the implementation percentage of the decentralized scheme; the vertical axis expresses the quantity in km³/y of water saved for the same final consumer demand as a function of the state of deterioration of the infrastructure

THIRD PHASE - financial perspective and feasibility

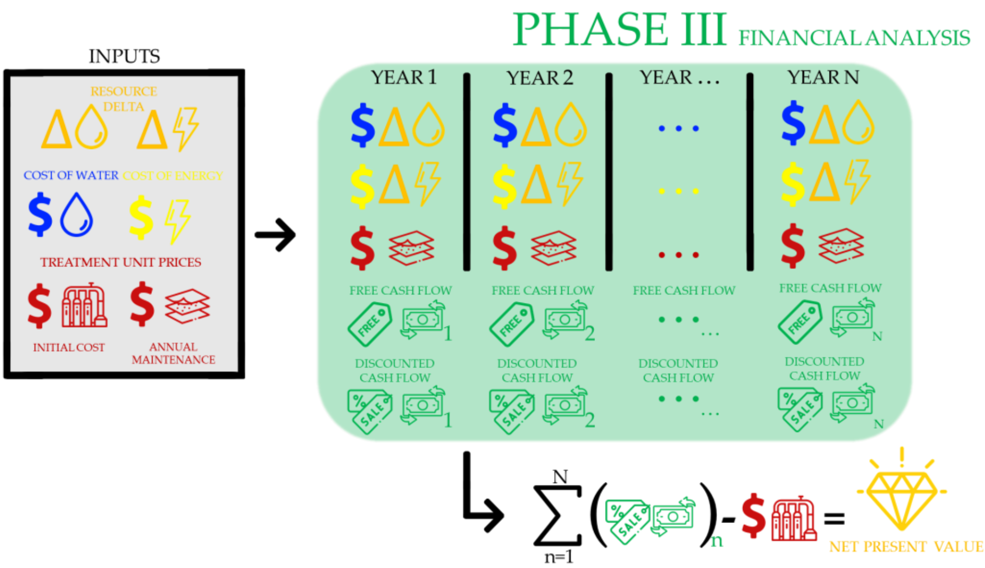


Fig. 29 Schematics of phase 3

The introduction of financial figures moves us to the third phase: evaluating the hybrid cycle's implementation feasibility. The prices to end-users of water and electric energy serve as proxies of the cost of the resources. To account for private for-profit companies operating in the sector, a mark-up percentage was considered to differentiate these costs for providers and regular citizens. In these paragraphs, the state will represent both the energy and water provider; this simplification helps to stay focused on the real values under investigation, water, and energy. These basic financial figures allow calculating the yearly value of the saved water and energy.

The two perspectives, state, and final user, in light of this change in paradigm, differ firstly because of the assumed mark-up applied to the cost of the resource but, most importantly, on the location of where the resources are consumed. In fact, in some cases, the total difference between cycles in terms of energetic resources used doesn't appear relevant. An example will help visualize this concept:

with the centralized water cycle the State authority sees a demand of 0,5 m3 of water each day from a specific household, no requirement from that household of energy linked to domestic water use (not considering heaters irrigators...), and a requirement of energy to carry around the cycle that same amount;

with the hybrid system, the same household, imagining that it reuses water to cover ~30% of its daily demand, to satisfy the same needs, requires 0,35 m3 of water plus the energy to recycle 0,15 m3, furthermore the central authority has the demand of energy to manage those 0,35 m3 of water along the cycle. Hence, from an energetic perspective, electricity would still be outflowing to manage 1m3 of water; energy is only used in a different location with a possible increase or decrease equal to the delta between the two cycle's efficiencies, the two consumptions could energetically even net out. If the initiative is undertaken by private households without any subsidy, the country would benefit from this situation proportionally to the difference in consumption of both water and energy and additionally have to infrastructurally sustain an increased demand on the grid. On the opposite side, for single households, this would mean to carry the burden of the total energetic consumptions of their system.

Behind decentralizing energetic consumption lies the significant gain in the system's robustness. Energy and water are opposite sides of the same coin, with the main difference being that while freshwater is a limited resource and incredibly costly to transfer over long distances, energy is potentially unlimited and relatively to water, substantially easier to relocate. The value of these savings serves as the budget to verify the affordability of the implementation plan.

The result of this third phase is the NPV of the decentralization scheme; this will be evaluated from the two perspectives, the state's and the household's. The central authority, in light of the benefits, pointed out, could evaluate the investment option through subsidies to households and have both a financial and an environmental gain.

Other than differing for the yearly energy value, the state enjoys a significant discount applied in full on the initial unit acquisition and halved for yearly membrane substitution. In fact, it was assumed that if the government decides to implement such a plan on a large scale, bulk purchases will result in a lower cost per unit. Furthermore, while the total quantity of units acquired will treat the same percentage of water, the state's computation will see the purchase of only 9m3/d units that have a lower price per m3. In the case of household purchases, the situation is slightly less financially inviting; different household agglomerations have a varying production of greywater. The present value of savings will be the combined budget of the number of households that generate the greywater demand closest to the capacity of the next available unit size(e.g., each household requires 110 l/d of treated greywater, for five households the combined total is 990l/d. Therefore, NPV to acquire a 1m3/day unit will consider only the five individual household savings as free cash flows rather than rounding the number to the closest unit). Concerning the discount rate to compute the present value, the hypothesis made was 8%. Because of the type of technology selected in the previous chapter, yearly expenditures were straight forward with one membrane per 3m3 of water treated a day and a 10% pump fault probability. Each country enters the NPV calculation with its financial inputs of price, growth rates, and potentially a different discount rate. NPV is calculated for three periods, five, ten, and fifteen years. For independent implementation by households, NPV is computed even for the other unit sizes.

Price values of both energy and water, resulting in an NPV equal to zero were found through excel's goal seek function. More than the price gap between these two resources, which made the cost of energy practically irrelevant was the proportion between water and energy quantities, especially in the case of State implementation.

The main conclusion drawn by the study of the financial aspect of decentralization and the prices of water and energy is the fact that implementation, especially with the selected technology, requires higher water tariffs. The calculations, always for comparative reasons, were done using the modeled consumption rather than the actual one. This provides comparability between the different nations and furthermore, is almost in every case a worst-case scenario. For example, if in the United States the technology is implementable with an average consumption of about one-third of the actual one, the real advantage would only be higher.

FOURTH PHASE - future outlook

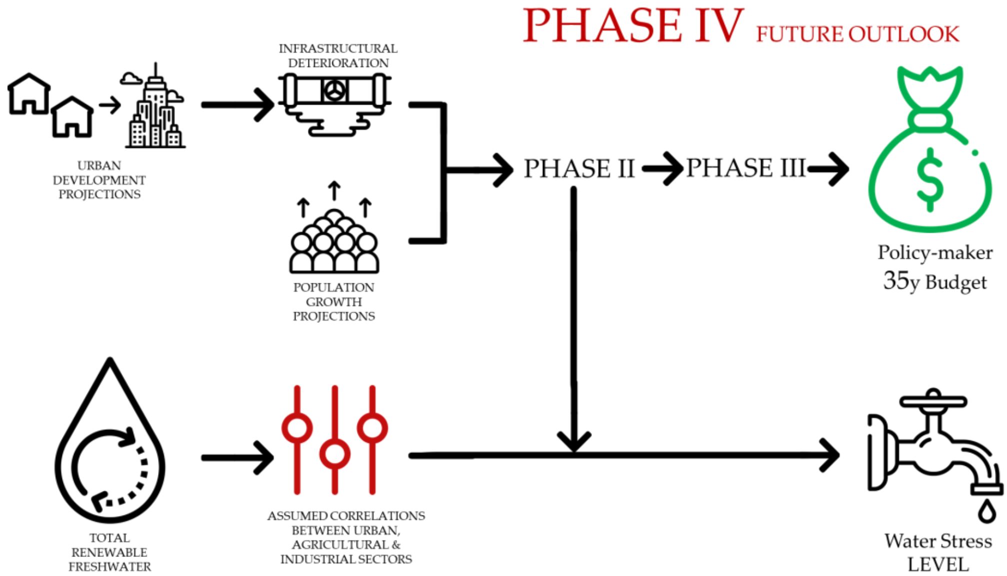


Fig. 30 Schematics of phase 4

After verifying whether the hybrid cycle can be implemented or not, the attention now shifts on the growth pattern of the subject under scrutiny. The evaluation of growth is based on two key assumptions, one on consumption trends and the other on the risk associated with the centralized cycle.

Depending on the GREEN or RED scenario we are in, consumption patterns will remain as such in the former case while, if currently, the urban population consumes less than the modeled value, an increase in consumption is projected. This will happen linearly, reaching par in 2050. As mentioned in the first paragraph of this section, we assume that sooner or later, the estimated consumption figure will be the minimum above which consumption will stabilize for everyone.

Regarding the quantification of the risk linked to centralized water management, as stated on various occasions in the second and third chapters, a significant fragility of the centralized cycle, is the distribution network. Both because of its complexity and the high costs of maintenance, it is not very responsive, especially to abrupt increases in population. To factor these aspects, city size was considered. In the early stages of the model, city size was analyzed to extrapolate some correlation with density; this did not turn out to be the case. The correlation would have indicated the economies of scale that could have been tapped in by agglomerating a more significant number of households and building packaged plants with new technologies that are even more efficient, especially regarding the pumping units. However, cities vary significantly even within the same neighborhood a few kilometers apart, and they vary even more when considering different geographies; hence, the initiative was abandoned in the model but is definitely something to exploit once the problem is localized.

The city size, intended as the number of inhabitants, found its correlation with the stress level to which the distribution network is subject. A fast-growing city will have a distribution network always trying to catch up. The bigger the size of the city and the more this assumption holds. Leakages in the network are used as a proxy for the cycle's inefficiencies. The assumption is that smaller cities are more manageable than large ones because of lower complexity, and here population growth, in relative terms, does not constitute a significant threat to the cycle's integrity. The quantification of this phenomenon was computed with the help of a polynomial equation, which can be adjusted freely. For benchmarking purposes the assumed equation takes the shape of a quadratic equation with its stationary point in zero and having a set value of 0,2 or 20% where the variable on the x-axis, which in this case is the number of dwellers per city, is equal to ten thousand which represents the cities with ten million inhabitants. Hence the number of inhabitants set a leakage coefficient. Relative variations in the size of cities in percentage points, multiply this coefficient and add it up to the existing number. Projections on city size are, as for now, available only until 2035; for the remaining period, the decision was to consider a linear decline in the growth rate until it reaches zero at the end of 2050.

Changes in consumption patterns and progressive failure of the distribution network in combination with population growth are evaluated for thirty-five years for both the centralized cycle and the hybrid cycle. The two are compared for both water and energy consumptions with a financial evaluation using the present value of the consumption and the losses.

The model provides two final figures indicating the total financial value of resources lost in both cycles and the stress level of the yearly renewable water resources. The latter is an approximation that uses the same allocation of resources implicated in the initial estimate corrected progressively as the population changes. The reasoning behind this is that industrial and agricultural activities will follow the direction established by population variations, hence the assumption of direct correlation with relative population growth. In the model, this assumption takes the form of a ratio between population growth and the percentage of water destined to domestic use. The value of this ratio is decided by the user, while the model provides the growth figure hence finding a new percentage of withdrawal for domestic use. This figure sets the base to back engineer the total amount withdrawn. For consistency and comparability, both with the past and the alternative hybrid scenario, the calculation is performed starting from the actual forecasted water demand originating from the centralized cycle scenario.

Results

To show the capabilities of this model it has been applied to selected countries based on their demographic relevance in their sub-region. All the world's subregions have been analyzed (fig 31). The results shown come directly from the model and the analysis was performed with the same consumption figures for all the countries and no discounts were applied to either initiatives. This can be changed at will in the model.

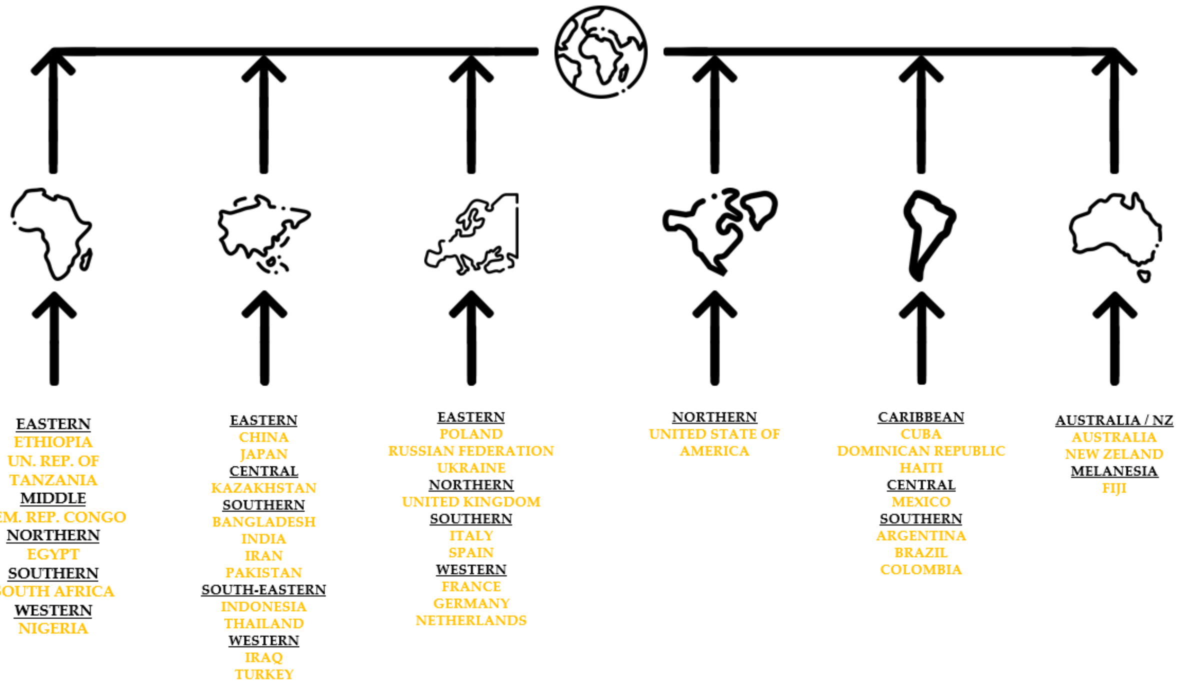


Fig. 31 Overview of the application of the model; the starting point are the countries results which are then weighted to form regional, continent and world results

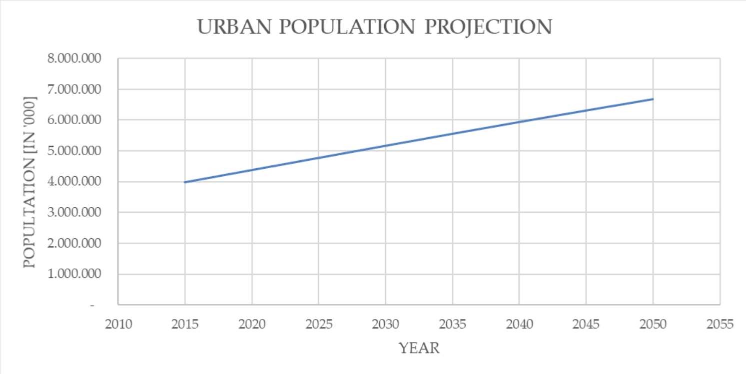
The results obtainable from the model will be shown via two examples of those obtained in this specific application: first two RED countries, constituting the Eastern Africa region and secondly two GREEN countries, constituting the Southern European region, all the others are presented in exhibit 1 with their own summary table.

For the purpose of better understanding the results the summarizing table is divided in two sections.

The first assesses the current state of potential implementation from a financial perspective and provides a "YES/NO" answer to whether the initiative can be implemented by the government or by the single households independently. For the result to be positive, at least one of the entities in the area under investigation must be a "YES". The other five results in this first result section are obtained via an automatic GOALSEEK function which, based on the local inputs, provides the minimum value for the initiative to be implemented. For "higher" entities, such as regions and continents, a weighted average, based on the population, is computed.

The second part makes projections until 2050 providing a quantitative and financial evaluation of moving forward with or without implementing the hybrid cycle. Both these points of view are useful in order to grasp the magnitude of future investments in light of the savings that can be obtained. The bottom-line displays the relative quantity of annually renewable freshwater that is withdrawn for all human activities combined. The color code indicates where there can be a problem if no change in urban water management happens. The threshold was set to 70% of utilization for the starting unit of the model, in this case, the single countries. All the higher entities' color is determined by those of which there are composed(e.g. the global bottom-line is red even if the withdrawal is ~30%, this is because for instance in Spain the value is ~72%; on the other hand Eastern Europe is green because the three analyzed countries in that specific region(Russia, Poland and Ukraine have respectively values equal to 25%, 2%, 16%).

WORLD



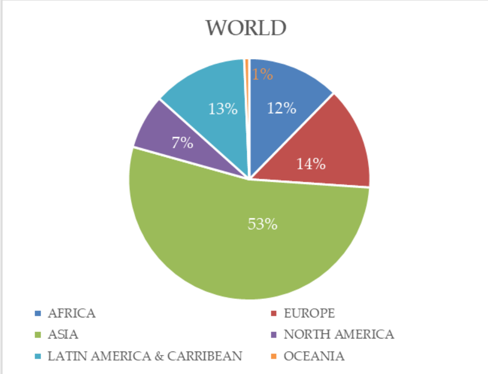
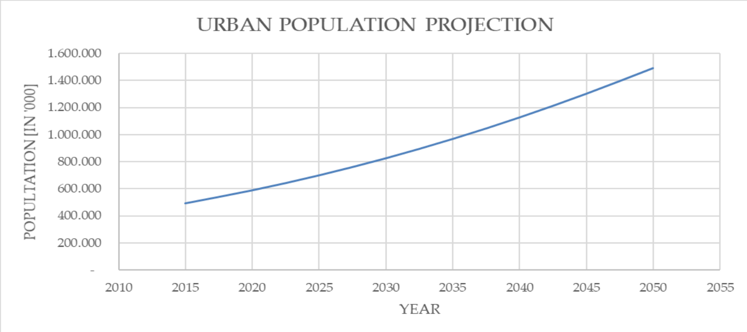


Fig. 32 – Urban Population Projection

Table 19 – Model Results

WORLD RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	0,68
min WATER price Growth rate for NPV>=0		6%
min ENERGY PRICE for NPV>=0	$	1,25
min ENERGY price Growth rate for NPV>=0		-32%
min 9m3/day treatment unit price	$	9.313
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		30,91
avg actual domestic demand 2015-2050 HC [km3/year]		21,30
DELTA		-31%
avg actual energy demand in CC [GWh/year]		32.219
avg actual energy demand in HC [GWh/year]		29.199
DELTA		-9%
PV of water lost in CC	B$	-5.310
PV of water lost in HC	B$	-3.672
PV of water savings with HC in 35years	B$	1.638
PV of energy consumed in CC	B$	898
PV of energy consumed in HC	B$	802
PV of energy expenditure if adoptiong HC for next 35years	B$	-97
WATER STRESS LEVEL(% of renewable resource used)		30%

AFRICA



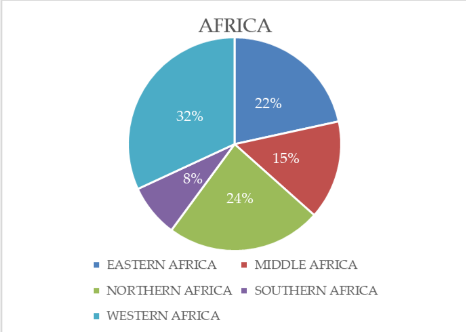
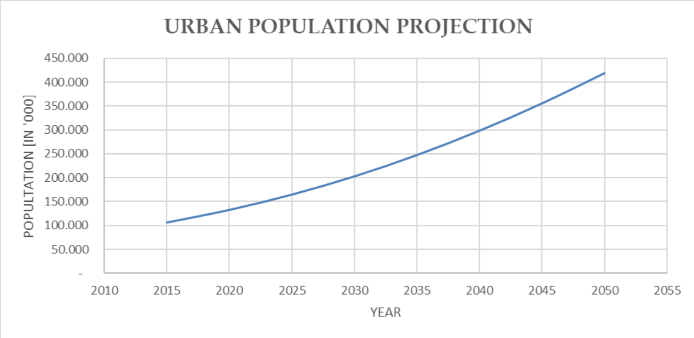


Fig. 33 – Urban Population Projection

Table 20 – Model Results

AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,04
min WATER price Growth rate for NPV>=0		19%
min ENERGY PRICE for NPV>=0	$	5,65
min ENERGY price Growth rate for NPV>=0		49%
min 9m3/day treatment unit price	$	-19.176
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		20,38
avg actual domestic demand 2015-2050 HC [km3/year]		13,77
DELTA		-32%
avg actual energy demand in CC [GWh/year]		17.833
avg actual energy demand in HC [GWh/year]		15.846
DELTA		-11%
PV of water lost in CC	M$	-518.342
PV of water lost in HC	M$	-350.310
PV of water savings with HC in 35years	M$	168.032
PV of energy consumed in CC	M$	129.788
PV of energy consumed in HC	M$	113.166
PV of energy expenditure if adoptiong HC for next 35years	M$	-16.622
WATER STRESS LEVEL(% of renewable resource used)		89%

EASTERN AFRICA



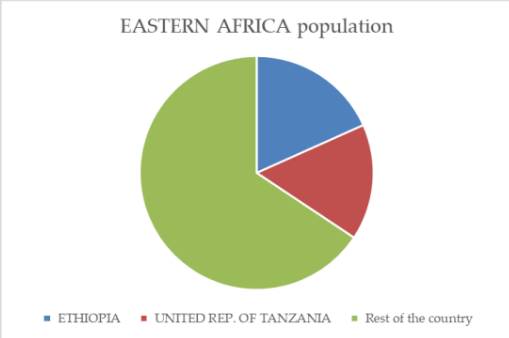


Fig. 34 – Urban Population Projection

Table 21 – Model Results

EASTERN AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,04
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	3,77
min ENERGY price Growth rate for NPV>=0		42%
min 9m3/day treatment unit price	$	-23.754
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		12,40
avg actual domestic demand 2015-2050 HC [km3/year]		8,27
DELTA		-33%
avg actual energy demand in CC [GWh/year]		12.338
avg actual energy demand in HC [GWh/year]		10.986
DELTA		-11%
PV of water lost in CC	M$	-60.813
PV of water lost in HC	M$	-40.409
PV of water savings with HC in 35years	M$	20.404
PV of energy consumed in CC	M$	26.785
PV of energy consumed in HC	M$	23.420
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.365
WATER STRESS LEVEL(% of renewable resource used)		47%

ETHIOPIA - EASTERN AFRICA

At a Glance

Fig. 35 illustrates the projected change in population in Ethiopia, while table 22 summarizes the main outputs of the model.

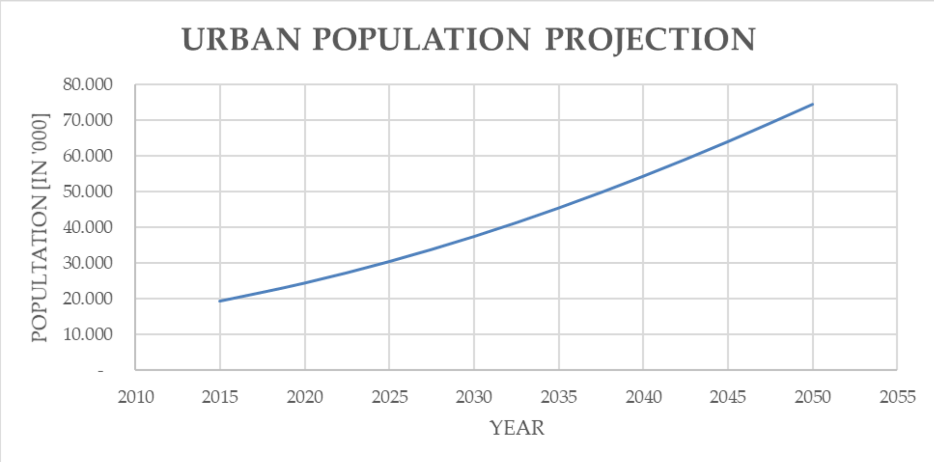


Fig. 35 – Urban Population Projection

Table 22 – Model Results

ETHIOPIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,18
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	5,13
min ENERGY price Growth rate for NPV>=0		47%
min 9m3/day treatment unit price	$	-24.189
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,52
avg actual domestic demand 2015-2050 HC [km^3/year]		1,03
DELTA		-33%
avg actual energy demand in CC [GWh/year]		1.617
avg actual energy demand in HC [GWh/year]		1.522
DELTA		-6%
PV of water lost in CC	M$	-6.068
PV of water lost in HC	M$	-4.097
PV of water savings with HC in 35years	M$	1.971
PV of energy consumed in CC	M$	2.144
PV of energy consumed in HC	M$	2.015
PV of energy expenditure if adoptiong HC for next 35years	M$	-128
WATER STRESS LEVEL(% of renewable water resource used)		38%

PHASE 1

Figures 36 and 37 respectively show the results from the first phase of the model:

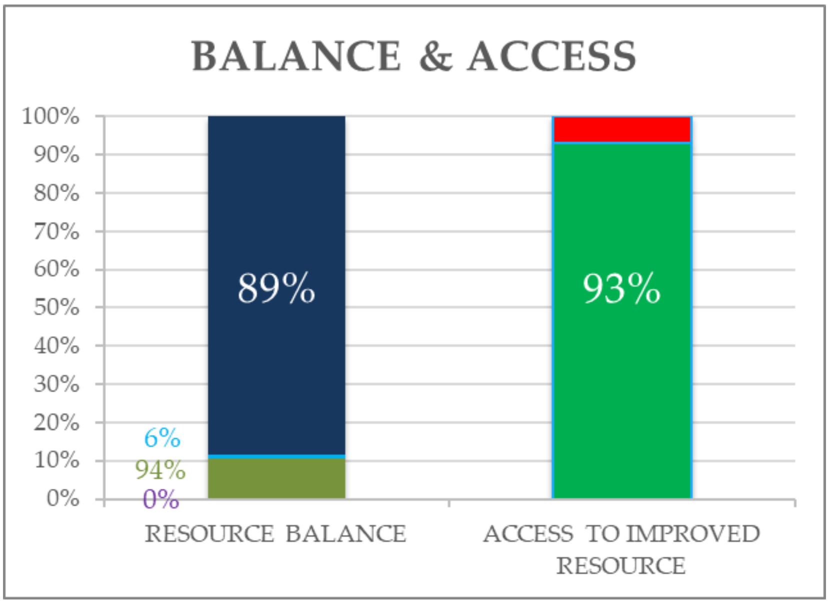


Fig. 36 - On the left, total yearly renewable water available(dark blue, absolute percentage), withdrawal for domestic use(light blue), for agricultural use(green), and industrial use(purple) and respective relative percentages with respect to the total withdrawn; On the right the percentage of the urban population with access to improved water sources.

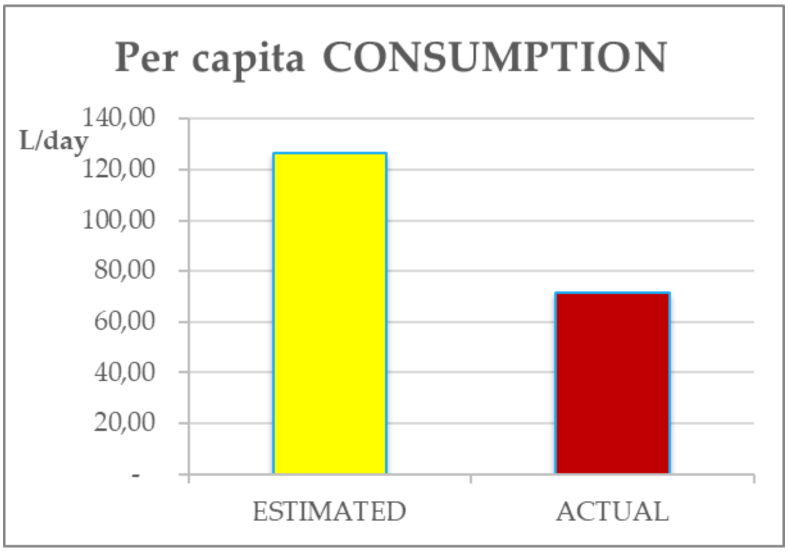


Fig. 37 - Graphic comparison between estimated and actual per capita consumption;

PHASE 2

In order to satisfy this consumer demand, the water and electric energy requirements vary depending on the typology of the urban hydrologic cycle.

Figures 38 and 39 respectively compare these aspects:

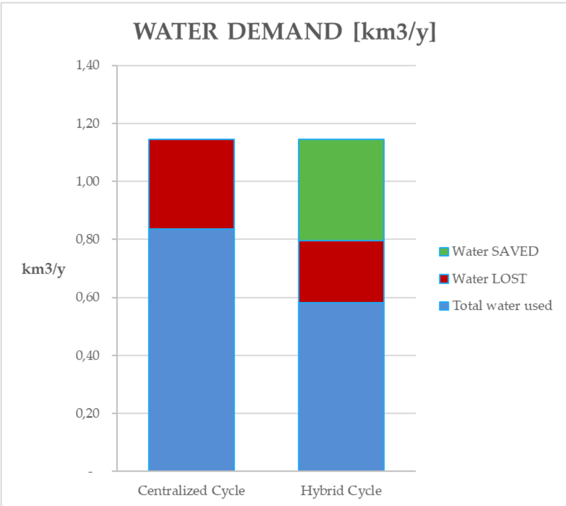


Fig. 38 WATER demand

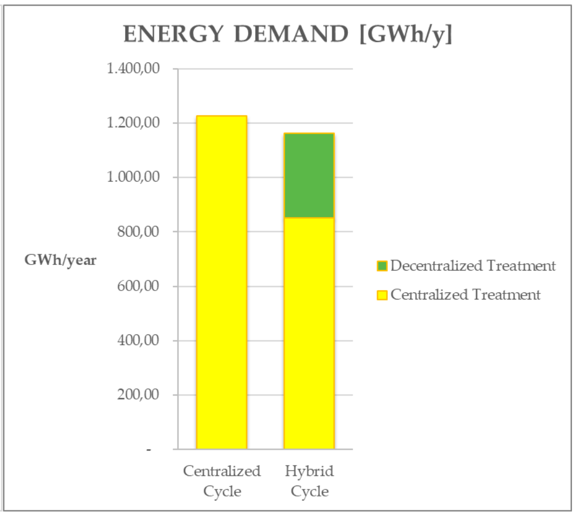


Fig. 39 ENERGY demand

Consumption divides the energetic requirements in two macro stages, upstream and downstream. Table 23 computes the impact of a relative increase in energetic efficiency.

Table 23 in both quantitative figures and percentages for easier comparison

Total ENERGY demand in CC [GWh/year]		Raw water treatment & distribution						
		0,85	0,90	0,95	1,00	1,05	1,10	1,15
Collection & treatment	0,85	1.042	1.088	1.134	1.179	1.225	1.271	1.317
	0,90	1.057	1.103	1.149	1.195	1.241	1.287	1.332
	0,95	1.073	1.119	1.164	1.210	1.256	1.302	1.348
	1,00	1.088	1.134	1.180	1.226	1.272	1.317	1.363
	1,05	1.104	1.149	1.195	1.241	1.287	1.333	1.379
	1,10	1.119	1.165	1.211	1.257	1.302	1.348	1.394
	1,15	1.135	1.180	1.226	1.272	1.318	1.364	1.410

Values in %

Total ENERGY demand in CC [GWh/year]		Raw water treatment & distribution						
		85%	90%	95%	100%	105%	110%	115%
Collection & treatment	85%	-15%	-11%	-8%	-4%	0%	4%	7%
	90%	-14%	-10%	-6%	-3%	1%	5%	9%
	95%	-12%	-9%	-5%	-1%	2%	6%	10%
	100%	-11%	-7%	-4%	0%	4%	7%	11%
	105%	-10%	-6%	-2%	1%	5%	9%	12%
	110%	-9%	-5%	-1%	3%	6%	10%	14%
	115%	-7%	-4%	0%	4%	8%	11%	15%

In this case, it appears clear that the up-stream energetic consumption has a more significant impact on the total efficiency of the process, therefore, implying that the majority of investments should be targeting improvement in these stages. The reality is that most energy-intensive functions in the upstream stages require lifting water; hence there are physical barriers under which consumptions cannot fall. Because of this issue, fig. 40 and fig. 41 plot the variation of water and energy demand as a function of the state of deterioration of the infrastructure represented by the leakage percentage.

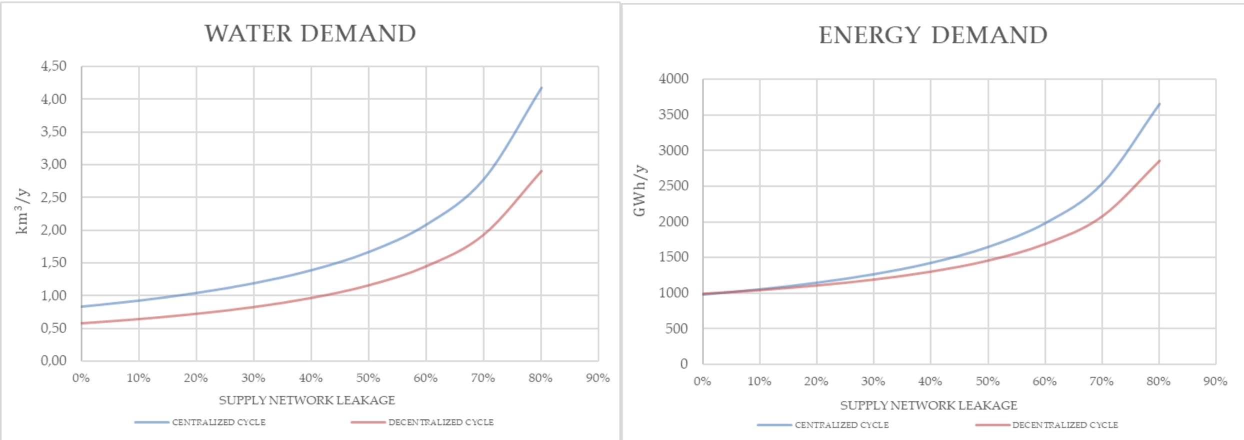


Fig. 40 & Fig. 41 Water and Energy demand as a function of both cycle type and infrastructural deterioration

Because of this, decentralized treatment performances need to be compared not only to centralized wastewater treatment but, more importantly, with the upstream energetic expenditure. Hence fig. 42 compares the effective energetic cost of upstream procurement and supply, net of the network losses, with the decentralized treatment consumption. When the former is higher than the latter, from a resource standpoint, the hybrid cycle adoption is a GO.

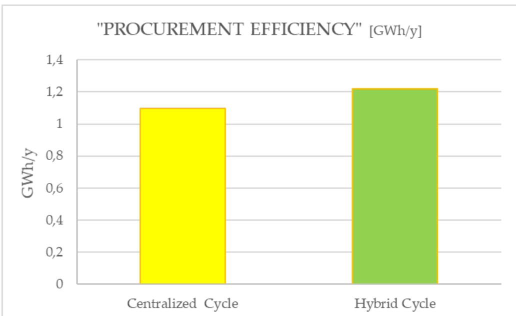


Fig. 42 Procurement efficiency; is water saved through greywater reuse more efficient than the process of procuring fresh water from traditional sources?

Whether this is the case or not, the financial analysis will have the last say.

PHASE 3

In Ethiopia the cost of water and energy are respectively 0.27 $ /m3 and 0.09 $/kWh. In the base case scenario, the hypothesis was to keep at zero both the energy and water growth rates. Furthermore, the discount rate is initially considered zero; taking these factors into account, the present value of the combined savings over 15 years is depicted in fig 43 while the project's NPV per household for both STATE and INDEPENDENT implementation in fig 44.

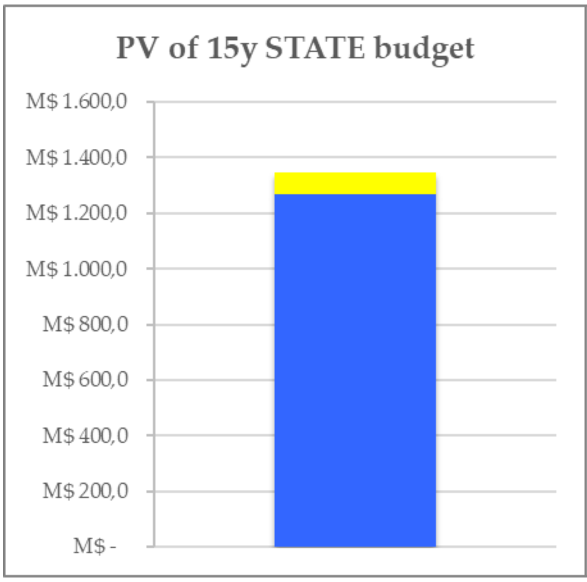


Fig. 43 PV of savings over 15 years

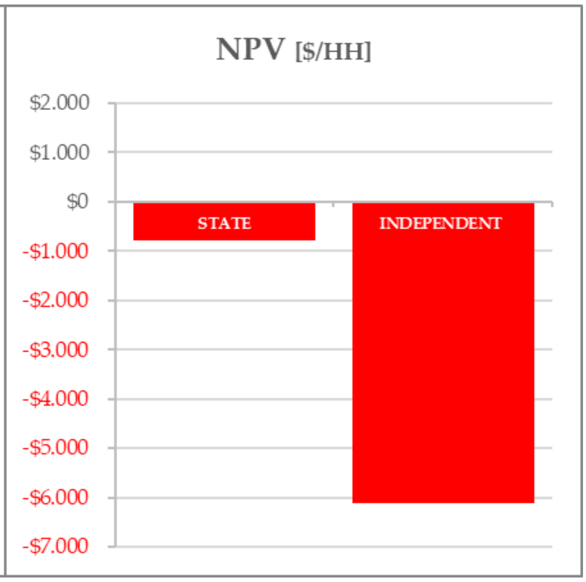


Fig. 44 NPV for a single household

The sensitivity analysis, performed with the help of tables 24 (water-energy cost), describes the combined value of savings depending on the cost of the resources.

Table 24 Total yearly savings[M$] (State POV)

Total yearly SAVINGS (STATE) [M$/y]		Cost of WATER [$/m³]						
		0,27	0,42	0,57	0,73	0,88	1,03	1,18
Cost of ENERGY [$/kWh]	0,09	M$ 90	M$ 138	M$ 185	M$ 233	M$ 281	M$ 329	M$ 376
	0,93	M$ 138	M$ 185	M$ 233	M$ 281	M$ 329	M$ 376	M$ 424
	1,77	M$ 185	M$ 233	M$ 281	M$ 329	M$ 376	M$ 424	M$ 472
	2,62	M$ 233	M$ 281	M$ 329	M$ 377	M$ 424	M$ 472	M$ 520
	3,46	M$ 281	M$ 329	M$ 377	M$ 424	M$ 472	M$ 520	M$ 568
	4,30	M$ 329	M$ 377	M$ 424	M$ 472	M$ 520	M$ 568	M$ 615
	5,14	M$ 377	M$ 424	M$ 472	M$ 520	M$ 568	M$ 615	M$ 663

Because of the negative NPV, the following data tables will analyze the 15-year plan carried out with State grants, which will be the first initiative to breakeven. The independent variables taken into account are the cost of the resources and their respective annual growth rates.

Table 25 dependent variable, 15y project NPV ; independent variables: Cost of WATER, Cost of ENERGY

15y project NPV (STATE)		Cost of WATER [$/m³]						
		0,27	0,52	0,77	1,02	1,27	1,52	1,78
Cost of ENERGY [$/kWh]	0,09	M$ -4.294	M$ -3.113	M$ -1.933	M$ -752	M$ 428	M$ 1.609	M$ 2.789
	0,93	M$ -3.577	M$ -2.396	M$ -1.216	M$ -35	M$ 1.145	M$ 2.326	M$ 3.506
	1,77	M$ -2.860	M$ -1.679	M$ -499	M$ 682	M$ 1.862	M$ 3.043	M$ 4.223
	2,62	M$ -2.143	M$ -962	M$ 218	M$ 1.399	M$ 2.579	M$ 3.760	M$ 4.941
	3,46	M$ -1.426	M$ -245	M$ 935	M$ 2.116	M$ 3.297	M$ 4.477	M$ 5.658
	4,30	M$ -709	M$ 472	M$ 1.653	M$ 2.833	M$ 4.014	M$ 5.194	M$ 6.375
	5,14	M$ 9	M$ 1.189	M$ 2.370	M$ 3.550	M$ 4.731	M$ 5.911	M$ 7.092

Table 26 dependent variable, 15y project NPV ; independent variables: Cost of WATER & Growth Rate

15y project NPV (STATE)		Cost of WATER [$/m³]						
		0,27	0,52	0,77	1,02	1,27	1,52	1,78
Cost of WATER growth rate	0,00	M$ -4.294	M$ -3.113	M$ -1.933	M$ -752	M$ 428	M$ 1.609	M$ 2.789
	0,03	M$ -3.968	M$ -2.485	M$ -1.002	M$ 481	M$ 1.965	M$ 3.448	M$ 4.931
	0,06	M$ -3.541	M$ -1.661	M$ 219	M$ 2.100	M$ 3.980	M$ 5.860	M$ 7.740
	0,09	M$ -2.980	M$ -578	M$ 1.823	M$ 4.225	M$ 6.627	M$ 9.028	M$ 11.430
	0,12	M$ -2.242	M$ 845	M$ 3.932	M$ 7.019	M$ 10.105	M$ 13.192	M$ 16.279
	0,15	M$ -1.273	M$ 2.715	M$ 6.702	M$ 10.690	M$ 14.677	M$ 18.664	M$ 22.652
	0,18	M$ 0	M$ 5.170	M$ 10.340	M$ 15.510	M$ 20.679	M$ 25.849	M$ 31.019

Table 27 dependent variable, 15y project NPV ; independent variables: Cost of ENERGY & Growth Rate

15y project NPV (STATE)		Cost of ENERGY [$/kWh]						
		0,09	0,93	1,77	2,62	3,46	4,30	5,14
Cost of ENERGY growth rate	0,00	M$ -4.294	M$ -3.577	M$ -2.860	M$ -2.143	M$ -1.426	M$ -709	M$ 9
	0,08	M$ -4.228	M$ -2.895	M$ -1.561	M$ -228	M$ 1.106	M$ 2.439	M$ 3.773
	0,16	M$ -4.093	M$ -1.494	M$ 1.106	M$ 3.705	M$ 6.304	M$ 8.903	M$ 11.502
	0,24	M$ -3.816	M$ 1.373	M$ 6.562	M$ 11.751	M$ 16.939	M$ 22.128	M$ 27.317
	0,31	M$ -3.257	M$ 7.161	M$ 17.579	M$ 27.997	M$ 38.415	M$ 48.833	M$ 59.250
	0,39	M$ -2.149	M$ 18.632	M$ 39.413	M$ 60.194	M$ 80.975	M$ 101.756	M$ 122.537
	0,47	M$ 0	M$ 40.882	M$ 81.763	M$ 122.645	M$ 163.526	M$ 204.408	M$ 245.289

Tables 28 and 29 tackle the same problem but consider the initial cost variation of the cheapest equipment per m³ of water treated,9m³/day and the cost of water and energy.

Table 28 dependent variable, 15y project NPV ; independent variables: Cost of WATER, Cost of 9m³ treatment unit

15y project NPV (STATE)		Cost of WATER [$/m³]						
		0,27	0,52	0,77	1,02	1,27	1,52	1,78
9m³ Treatment UNIT $	$ 22.270	M$ -3.959	M$ -2.778	M$ -1.598	M$ -417	M$ 763	M$ 1.944	M$ 3.124
	$ 23.580	M$ -4.071	M$ -2.890	M$ -1.710	M$ -529	M$ 652	M$ 1.832	M$ 3.013
	$ 24.890	M$ -4.182	M$ -3.002	M$ -1.821	M$ -641	M$ 540	M$ 1.720	M$ 2.901
	$ 26.200	M$ -4.294	M$ -3.113	M$ -1.933	M$ -752	M$ 428	M$ 1.609	M$ 2.789
	$ 27.510	M$ -4.406	M$ -3.225	M$ -2.044	M$ -864	M$ 317	M$ 1.497	M$ 2.678
	$ 28.820	M$ -4.517	M$ -3.337	M$ -2.156	M$ -976	M$ 205	M$ 1.386	M$ 2.566
	$ 30.130	M$ -4.629	M$ -3.448	M$ -2.268	M$ -1.087	M$ 93	M$ 1.274	M$ 2.454

Table 29 dependent variable, 15y project NPV ; independent variables: Cost of ENERGY, Cost of 9m³ treatment unit

15y project NPV (STATE)		Cost of ENERGY [$/kWh]						
		0,09	0,93	1,77	2,62	3,46	4,30	5,14
9m³ Treatment UNIT $	$ 22.270	M$ -3.959	M$ -3.242	M$ -2.525	M$ -1.808	M$ -1.091	M$ -374	M$ 343
	$ 23.580	M$ -4.071	M$ -3.354	M$ -2.636	M$ -1.919	M$ -1.202	M$ -485	M$ 232
	$ 24.890	M$ -4.182	M$ -3.465	M$ -2.748	M$ -2.031	M$ -1.314	M$ -597	M$ 120
	$ 26.200	M$ -4.294	M$ -3.577	M$ -2.860	M$ -2.143	M$ -1.426	M$ -709	M$ 9
	$ 27.510	M$ -4.406	M$ -3.688	M$ -2.971	M$ -2.254	M$ -1.537	M$ -820	M$ -103
	$ 28.820	M$ -4.517	M$ -3.800	M$ -3.083	M$ -2.366	M$ -1.649	M$ -932	M$ -215
	$ 30.130	M$ -4.629	M$ -3.912	M$ -3.195	M$ -2.478	M$ -1.761	M$ -1.043	M$ -326

Based on these figures we can conclude that in this case there is still a long way to go before this project is financially feasible.

PHASE 4

In terms of actual city size and urban development forecast in Ethiopia, table 30 summarizes the situation while fig 45 provides a graphic representation on the hypothesis made to quantify the magnitude of the infrastructural deterioration proportionally to the speed of city growth as a function of their size. The quadratic equation used in this simulation is set to hit a value of 20% of relative increase for the rise of a new city of 10 million inhabitants.

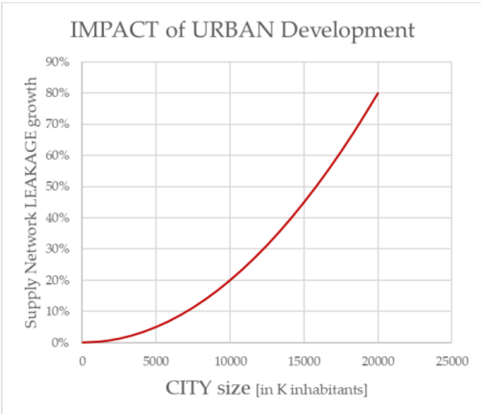
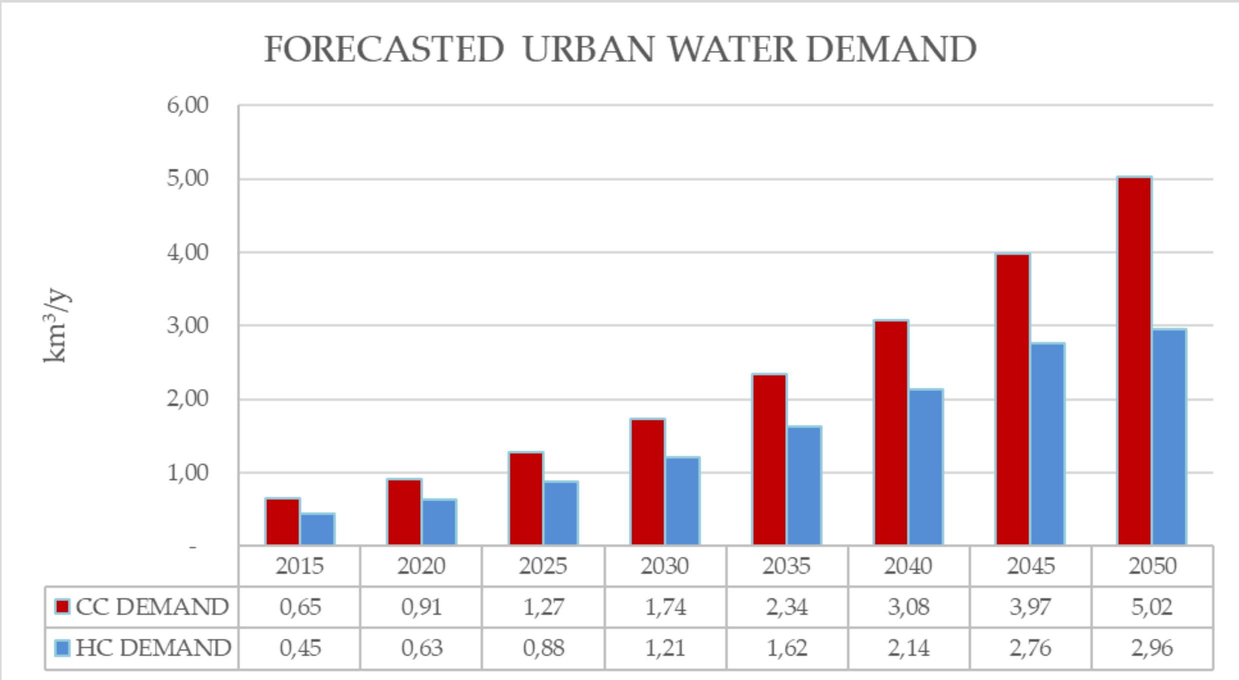


Fig. 45 Infrastructural deterioration as a function of city size

Table 30 Forecasted city size growth and resulting infrastructural deterioration

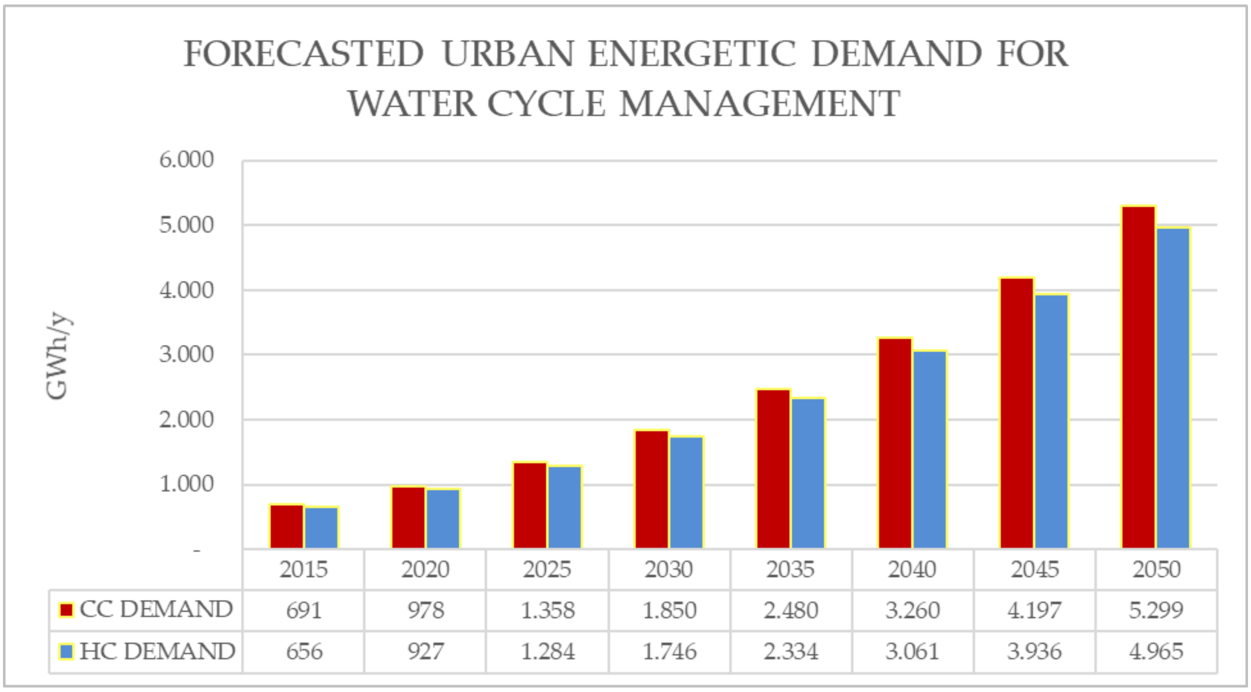
Data type	Size class	2015	2020	2025	2030	2035
Number of Agglomerations	10 million or more	0	0	0	0	0
Population	10 million or more	0	0	0	0	0
Number of Agglomerations	5 to 10 million	0	0	1	1	1
Population	5 to 10 million	0	0	5957	7352	8939
Number of Agglomerations	1 to 5 million	1	1	0	0	0
Population	1 to 5 million	3871	4465	0	0	0
Number of Agglomerations	500 000 to 1 million	0	1	2	4	6
Population	500 000 to 1 million	0	524	1144	2542	4107
Number of Agglomerations	300 000 to 500 000	3	3	4	4	6
Population	300 000 to 500 000	1077	1148	1595	1483	2101
Percentage of Urban Population	Fewer than 300 000	75%	74%	71%	70%	67%
Resulting Supply leakage VARIATION			0,67%	3,19%	2,63%	3,51%

Such computations are needed to forecast the water and consequent energetic demand for domestic consumption up to 2050 (fig 46 and fig 47).



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	0,65	0,91	1,27	1,74	2,34	3,08	3,97	5,02
HC DEMAND	0,45	0,63	0,88	1,21	1,62	2,14	2,76	2,96

Fig 46 Forecasted urban water demand



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	691	978	1.358	1.850	2.480	3.260	4.197	5.299
HC DEMAND	656	927	1.284	1.746	2.334	3.061	3.936	4.965

Fig 47 Forecasted urban energetic demand for water cycle management

Fig. 48 verifies how total water withdrawal from human activities, industrial, agricultural, and domestic, checks against the available renewable resource in Ethiopia.

The yellow line represents a cap set at 70% of the total value due to seasonality and the potential inaccessibility of the resource.

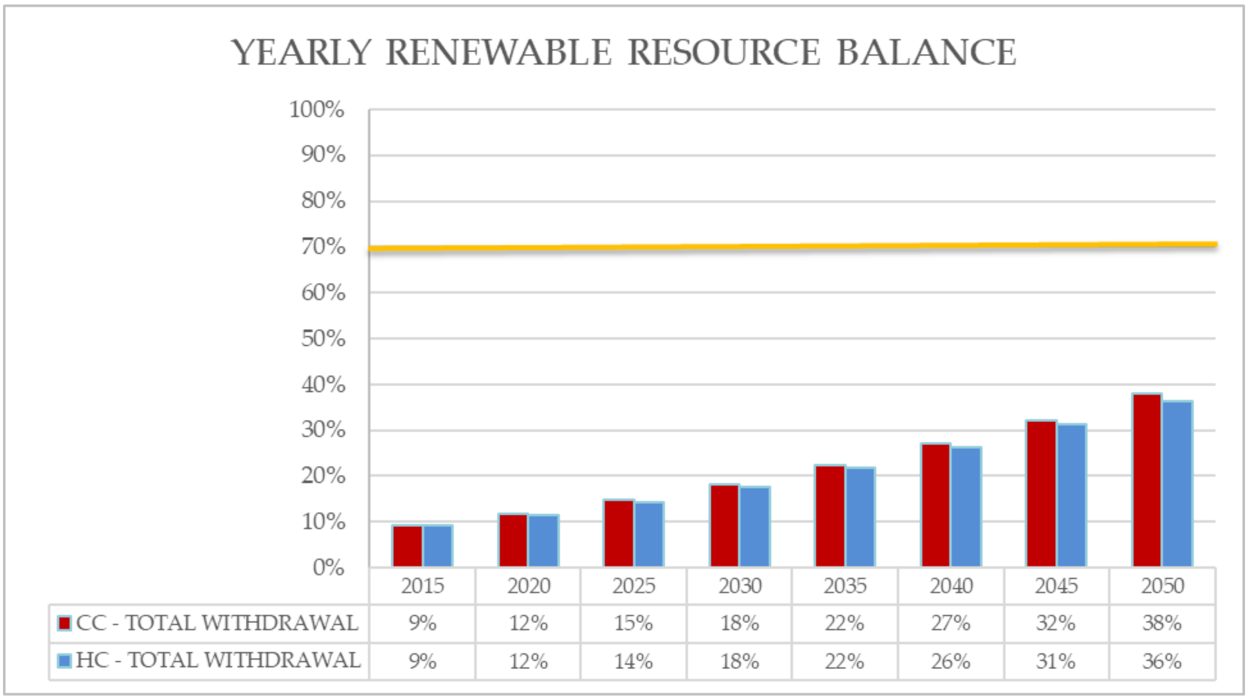


Fig 48 Yearly renewable resource balance

The 2015-2050 total estimated resources lost are highlighted in fig. 49

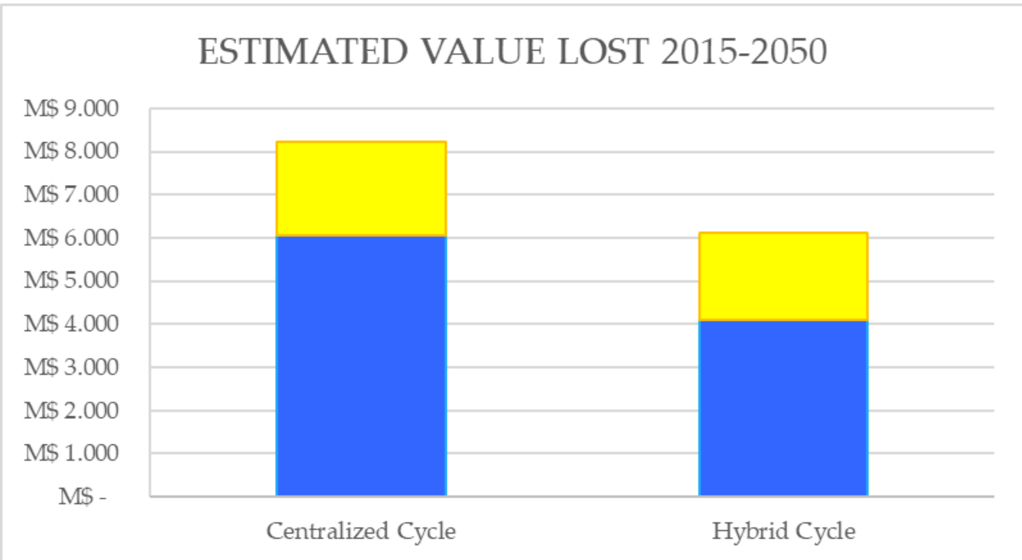


Fig 49 Estimated value lost 2015-2050

UNITED REPUBLIC OF TANZANIA - EASTERN AFRICA

At a Glance

Fig. 50 illustrates the projected change in population in United Republic of Tanzania, while table 31 summarizes the main outputs of the model.

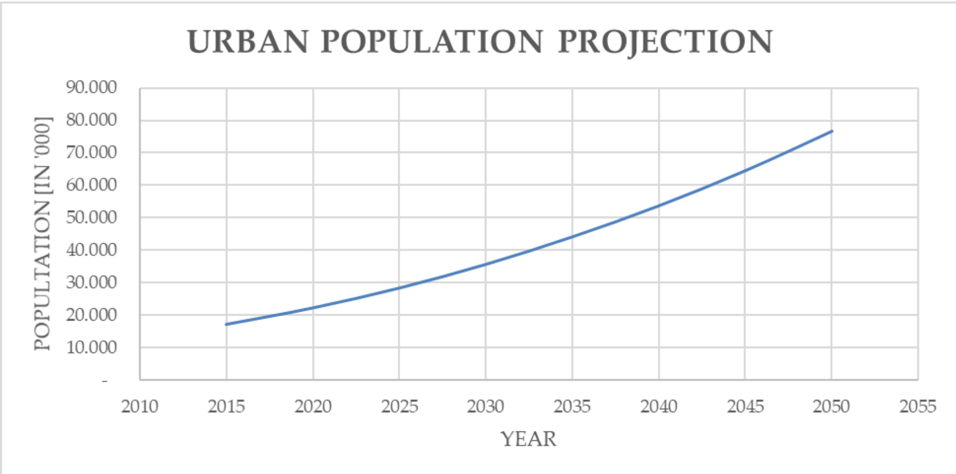


Fig 50 – Urban Population Projection

table 31 – Model Results

UNITED REPUBLIC OF TANZANIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,89
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	2,21
min ENERGY price Growth rate for NPV>=0		36%
min 9m3/day treatment unit price	$	-23.258
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		2,74
avg actual domestic demand 2015-2050 HC [km^3/year]		1,82
DELTA		-34%
avg actual energy demand in CC [GWh/year]		2.620
avg actual energy demand in HC [GWh/year]		2.251
DELTA		-14%
PV of water lost in CC	M$	-14.818
PV of water lost in HC	M$	-9.781
PV of water savings with HC in 35years	M$	5.037
PV of energy consumed in CC	M$	7.056
PV of energy consumed in HC	M$	6.028
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.027
WATER STRESS LEVEL(% of renewable water resource used)		57%

PHASE 1

Fig. 51 and fig. 52 respectively show the results from the first phase of the model:

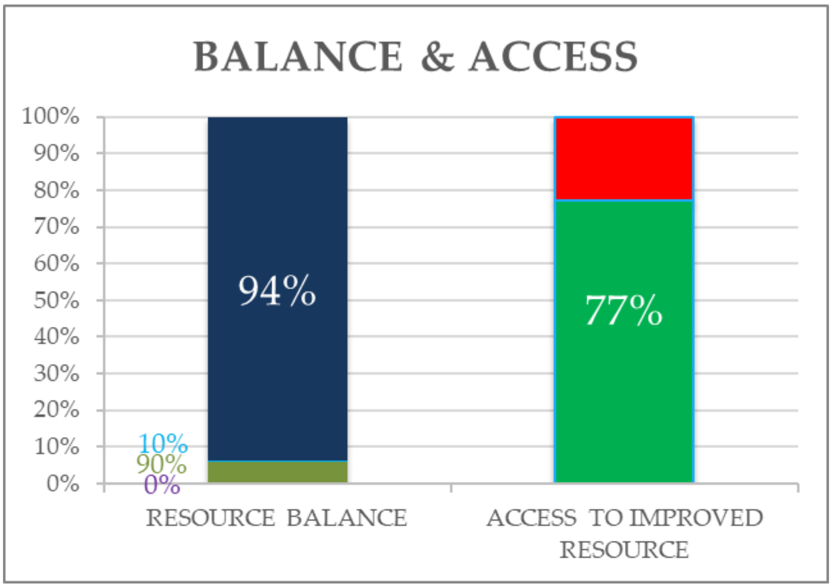


Fig. 51 - On the left, total yearly renewable water available(dark blue, absolute percentage), withdrawal for domestic use(light blue), for agricultural use(green), and industrial use(purple) and respective relative percentages with respect to the total withdrawn; On the right the percentage of the urban population with access to improved water sources.

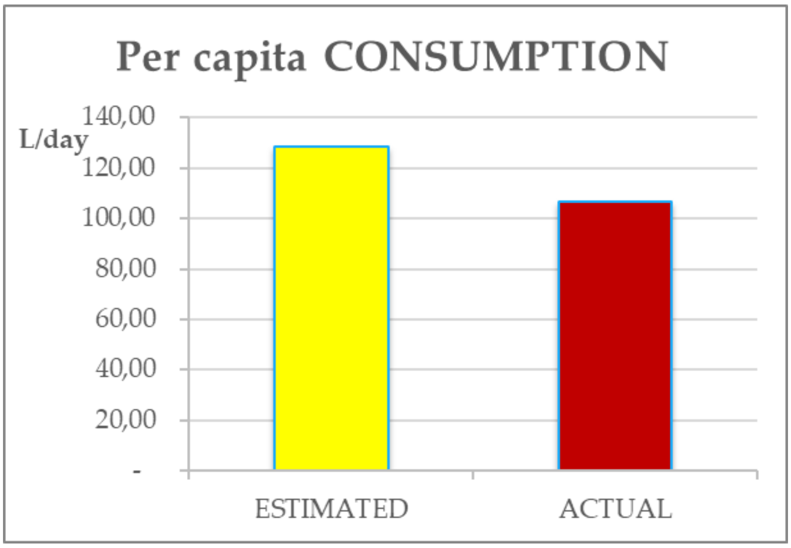


Fig. 52 - Graphic comparison between estimated and actual per capita consumption

PHASE 2

In order to satisfy this consumer demand, the water and electric energy requirements vary depending on the typology of the urban hydrologic cycle.

Fig. 53 and fig. 54 respectively compare these aspects:

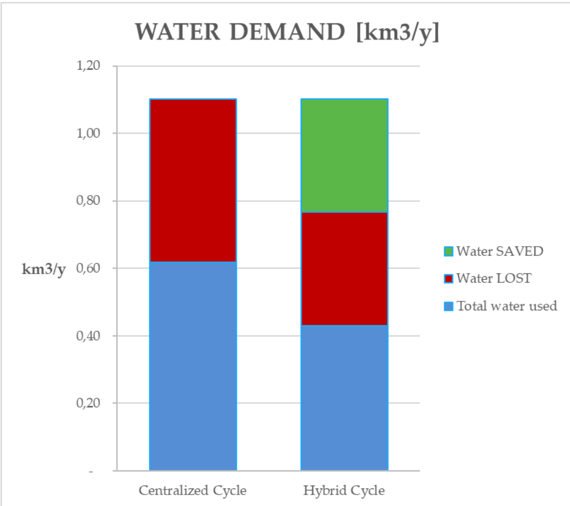


Fig. 53 WATER demand

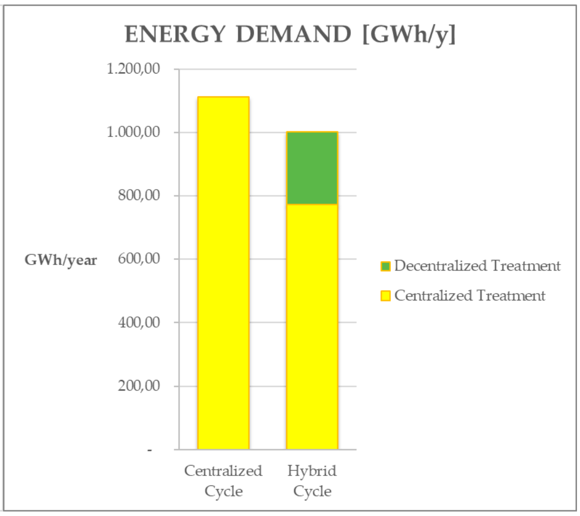


Fig. 54 ENERGY demand

Consumption divides the energetic requirements in two macro stages, upstream and downstream. Table 32 computes the impact of a relative increase in energetic efficiency.

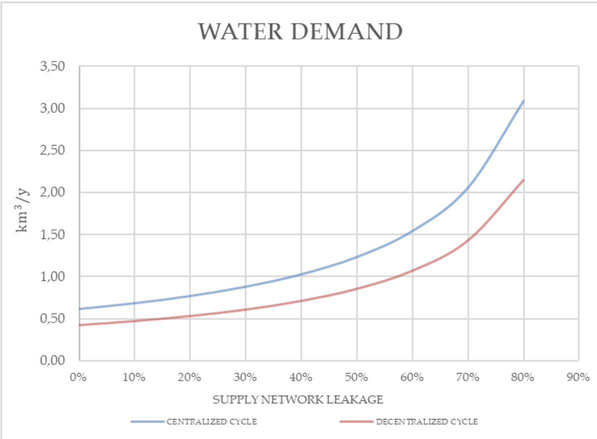
Table 32 in both quantitative figures and percentages for easier comparison

Total ENERGY demand in CC [GWh/year]		Raw water treatment & distribution						
		0,85	0,90	0,95	1,00	1,05	1,10	1,15
Collection & treatment	0,85	945	989	1.033	1.077	1.121	1.165	1.210
	0,90	956	1.000	1.044	1.089	1.133	1.177	1.221
	0,95	968	1.012	1.056	1.100	1.144	1.188	1.232
	1,00	979	1.023	1.067	1.111	1.156	1.200	1.244
	1,05	990	1.035	1.079	1.123	1.167	1.211	1.255
	1,10	1.002	1.046	1.090	1.134	1.178	1.223	1.267
	1,15	1.013	1.057	1.101	1.146	1.190	1.234	1.278

Values in %

Total ENERGY demand in CC [GWh/year]		Raw water treatment & distribution						
		85%	90%	95%	100%	105%	110%	115%
Collection & treatment	85%	-15%	-11%	-7%	-3%	1%	5%	9%
	90%	-14%	-10%	-6%	-2%	2%	6%	10%
	95%	-13%	-9%	-5%	-1%	3%	7%	11%
	100%	-12%	-8%	-4%	0%	4%	8%	12%
	105%	-11%	-7%	-3%	1%	5%	9%	13%
	110%	-10%	-6%	-2%	2%	6%	10%	14%
	115%	-9%	-5%	-1%	3%	7%	11%	15%

In this case, it appears clear that the up-stream energetic consumption has a more significant impact on the total efficiency of the process, therefore, implying that the majority of investments should be targeting improvement in these stages. The reality is that most energy-intensive functions in the upstream stages require lifting water; hence there are physical barriers under which consumptions cannot fall. Because of this issue, fig. 55 and fig. 56 plot the variation of water and energy demand as a function of the state of deterioration of the infrastructure represented by the leakage percentage.



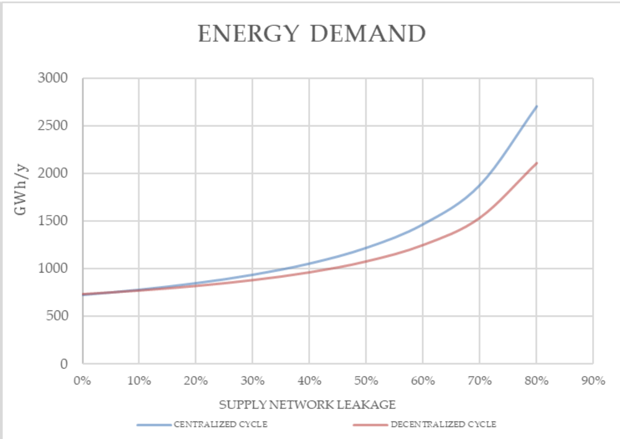


Fig. 55 & Fig. 56 Water and Energy demand as a function of both cycle type and infrastructural deterioration

Because of this, decentralized treatment performances need to be compared not only to centralized wastewater treatment but, more importantly, with the upstream energetic expenditure. Hence fig. 57 compares the effective energetic cost of upstream procurement and supply, net of the network losses, with the decentralized treatment consumption. When the former is higher than the latter, from a resource standpoint, the hybrid cycle adoption is a GO.

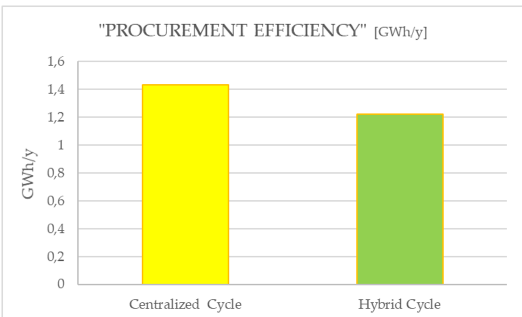


Fig. 57 Procurement efficiency; is water saved through greywater reuse more efficient than the process of procuring fresh water from traditional sources?

Whether this is the case or not, the financial analysis will have the last say.

PHASE 3

In United Republic of Tanzania the cost of water and energy are respectively 0.27 $ /m3 and 0.09 $/kWh. In the base case scenario, the hypothesis was to keep at zero both the energy and water growth rates. Furthermore, the discount rate is initially considered zero; taking these factors into account, the present value of the combined savings over 15 years is depicted in fig 58 while the project's NPV per household for both STATE and INDEPENDENT implementation in fig 59.

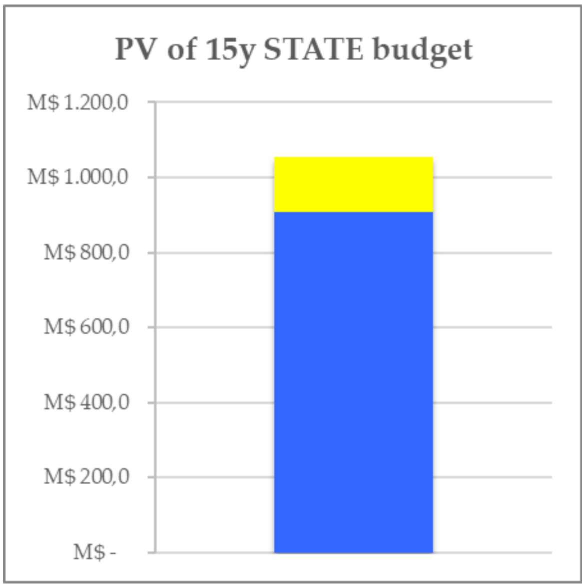


Fig. 58 PV of savings over 15 years

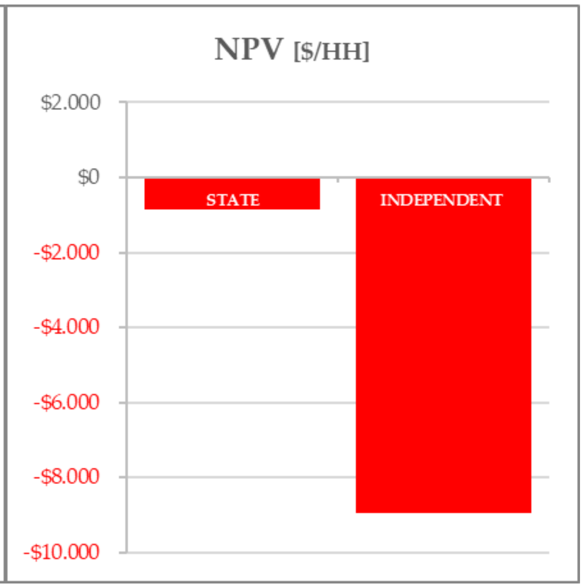


Fig. 59 NPV for a single household

The sensitivity analysis, performed with the help of tables 33 (water-energy cost), describes the combined value of savings depending on the cost of the resources.

Table 33 Total yearly savings[M$] (State POV)

Total yearly SAVINGS (STATE) [M$/y]		Cost of WATER [$/m³]						
		0,20	0,31	0,43	0,54	0,66	0,77	0,89
Cost of ENERGY [$/kWh]	0,10	M$ 70	M$ 105	M$ 140	M$ 174	M$ 209	M$ 244	M$ 278
	0,45	M$ 105	M$ 140	M$ 174	M$ 209	M$ 244	M$ 278	M$ 313
	0,81	M$ 140	M$ 174	M$ 209	M$ 244	M$ 278	M$ 313	M$ 348
	1,16	M$ 175	M$ 209	M$ 244	M$ 279	M$ 313	M$ 348	M$ 383
	1,51	M$ 209	M$ 244	M$ 279	M$ 313	M$ 348	M$ 383	M$ 417
	1,87	M$ 244	M$ 279	M$ 313	M$ 348	M$ 383	M$ 417	M$ 452
	2,22	M$ 279	M$ 314	M$ 348	M$ 383	M$ 418	M$ 452	M$ 487

Because of the negative NPV, the following data tables will analyze the 15-year plan carried out with State grants, which will be the first initiative to breakeven. The independent variables taken into account are the cost of the resources and their respective annual growth rates.

Table 34 dependent variable, 15y project NPV ; independent variables: Cost of WATER, Cost of ENERGY

15y project NPV (STATE)		Cost of WATER [$/m^3$]						
		0,20	0,39	0,58	0,77	0,95	1,14	1,33
Cost of ENERGY [$/kWh]	0,10	M$ -3.114	M$ -2.259	M$ -1.404	M$ -549	M$ 307	M$ 1.162	M$ 2.017
	0,45	M$ -2.593	M$ -1.738	M$ -882	M$ -27	M$ 828	M$ 1.684	M$ 2.539
	0,81	M$ -2.071	M$ -1.216	M$ -361	M$ 495	M$ 1.350	M$ 2.205	M$ 3.060
	1,16	M$ -1.550	M$ -695	M$ 161	M$ 1.016	M$ 1.871	M$ 2.727	M$ 3.582
	1,51	M$ -1.028	M$ -173	M$ 682	M$ 1.538	M$ 2.393	M$ 3.248	M$ 4.103
	1,87	M$ -507	M$ 349	M$ 1.204	M$ 2.059	M$ 2.914	M$ 3.770	M$ 4.625
	2,22	M$ 15	M$ 870	M$ 1.725	M$ 2.581	M$ 3.436	M$ 4.291	M$ 5.146

Table 35 dependent variable, 15y project NPV ; independent variables: Cost of WATER & Growth Rate

15y project NPV (STATE)		Cost of WATER [$/m^3$]						
		0,20	0,39	0,58	0,77	0,95	1,14	1,33
Cost of WATER growth rate	0,00	M$ -3.114	M$ -2.259	M$ -1.404	M$ -549	M$ 307	M$ 1.162	M$ 2.017
	0,03	M$ -2.880	M$ -1.803	M$ -727	M$ 350	M$ 1.426	M$ 2.503	M$ 3.580
	0,06	M$ -2.571	M$ -1.204	M$ 163	M$ 1.531	M$ 2.898	M$ 4.266	M$ 5.633
	0,09	M$ -2.165	M$ -415	M$ 1.335	M$ 3.086	M$ 4.836	M$ 6.586	M$ 8.337
	0,12	M$ -1.631	M$ 624	M$ 2.879	M$ 5.133	M$ 7.388	M$ 9.643	M$ 11.898
	0,15	M$ -927	M$ 1.992	M$ 4.911	M$ 7.830	M$ 10.750	M$ 13.669	M$ 16.588
	0,18	M$ 0	M$ 3.793	M$ 7.586	M$ 11.379	M$ 15.172	M$ 18.965	M$ 22.759

Table 36 dependent variable, 15y project NPV ; independent variables: Cost of ENERGY & Growth Rate

15y project NPV (STATE)		Cost of ENERGY [$/kWh]						
		0,10	0,45	0,81	1,16	1,51	1,87	2,22
Cost of ENERGY growth rate	0,00	M$ -3.114	M$ -2.593	M$ -2.071	M$ -1.550	M$ -1.028	M$ -507	M$ 15
	0,06	M$ -3.026	M$ -2.190	M$ -1.355	M$ -519	M$ 316	M$ 1.151	M$ 1.987
	0,12	M$ -2.871	M$ -1.491	M$ -111	M$ 1.270	M$ 2.650	M$ 4.030	M$ 5.411
	0,18	M$ -2.603	M$ -276	M$ 2.051	M$ 4.378	M$ 6.705	M$ 9.032	M$ 11.359
	0,24	M$ -2.140	M$ 1.824	M$ 5.788	M$ 9.752	M$ 13.716	M$ 17.680	M$ 21.645
	0,30	M$ -1.346	M$ 5.424	M$ 12.195	M$ 18.965	M$ 25.735	M$ 32.506	M$ 39.276
	0,36	M$ -0	M$ 11.529	M$ 23.058	M$ 34.586	M$ 46.115	M$ 57.644	M$ 69.173

Tables 37 and 38 tackle the same problem but consider the initial cost variation of the cheapest equipment per m3 of water treated,9m3/day and the cost of water and energy.

Table 37 dependent variable, 15y project NPV ; independent variables: Cost of WATER, Cost of 9m³ treatment unit

15y project NPV (STATE)		Cost of WATER [$/m^3]						
		0,20	0,39	0,58	0,77	0,95	1,14	1,33
9m^3 Treatment UNIT $	$ 22.270	M$ -2.867	M$ -2.012	M$ -1.156	M$ -301	M$ 554	M$ 1.409	M$ 2.265
	$ 23.580	M$ -2.949	M$ -2.094	M$ -1.239	M$ -384	M$ 472	M$ 1.327	M$ 2.182
	$ 24.890	M$ -3.032	M$ -2.177	M$ -1.321	M$ -466	M$ 389	M$ 1.245	M$ 2.100
	$ 26.200	M$ -3.114	M$ -2.259	M$ -1.404	M$ -549	M$ 307	M$ 1.162	M$ 2.017
	$ 27.510	M$ -3.197	M$ -2.342	M$ -1.486	M$ -631	M$ 224	M$ 1.080	M$ 1.935
	$ 28.820	M$ -3.279	M$ -2.424	M$ -1.569	M$ -713	M$ 142	M$ 997	M$ 1.852
	$ 30.130	M$ -3.362	M$ -2.507	M$ -1.651	M$ -796	M$ 59	M$ 915	M$ 1.770

Table 38 dependent variable, 15y project NPV ; independent variables: Cost of ENERGY, Cost of 9m³ treatment unit

15y project NPV (STATE)		Cost of ENERGY [$/kWh]						
		0,10	0,45	0,81	1,16	1,51	1,87	2,22
9m^3 Treatment UNIT $	$ 22.270	M$ -2.867	M$ -2.345	M$ -1.824	M$ -1.302	M$ -781	M$ -259	M$ 262
	$ 23.580	M$ -2.949	M$ -2.428	M$ -1.906	M$ -1.385	M$ -863	M$ -342	M$ 180
	$ 24.890	M$ -3.032	M$ -2.510	M$ -1.989	M$ -1.467	M$ -946	M$ -424	M$ 97
	$ 26.200	M$ -3.114	M$ -2.593	M$ -2.071	M$ -1.550	M$ -1.028	M$ -507	M$ 15
	$ 27.510	M$ -3.197	M$ -2.675	M$ -2.154	M$ -1.632	M$ -1.111	M$ -589	M$ -68
	$ 28.820	M$ -3.279	M$ -2.758	M$ -2.236	M$ -1.715	M$ -1.193	M$ -672	M$ -150
	$ 30.130	M$ -3.362	M$ -2.840	M$ -2.319	M$ -1.797	M$ -1.276	M$ -754	M$ -233

Based on these figures we can conclude that in this case there is still a long way to go before this project is financially feasible.

PHASE 4

In terms of actual city size and urban development forecast in United Republic of Tanzania, table 39 summarizes the situation while fig 60 provides a graphic representation on the hypothesis made to quantify the magnitude of the infrastructural deterioration proportionally to the speed of city growth as a function of their size. The (linear, quadratic, cubic…) equation used in this simulation is set to hit a value of 20%*** of relative increase for the rise of a new city of 10 million inhabitants.

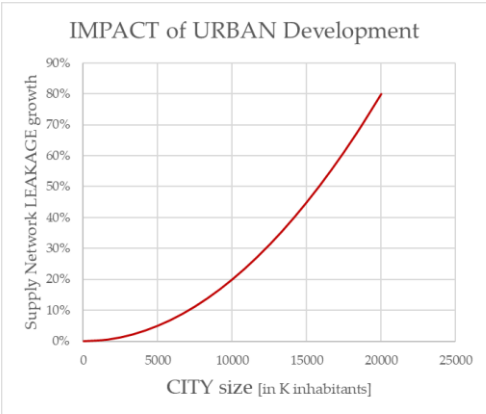
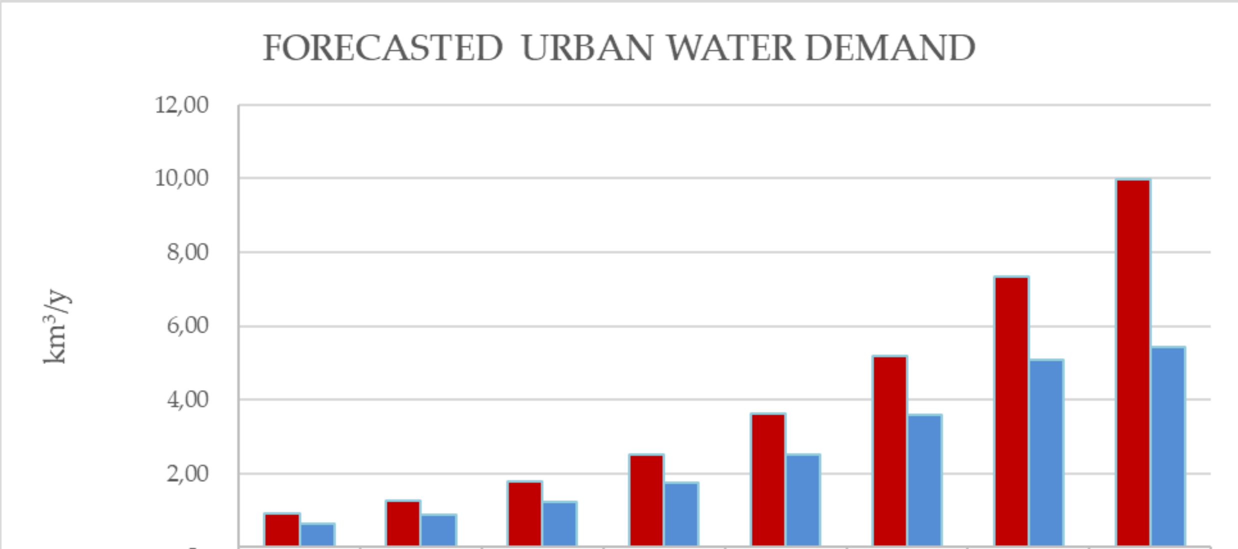


Fig. 60 Infrastructural deterioration as a function of city size

Table 39 Forecasted city size growth and resulting infrastructural deterioration

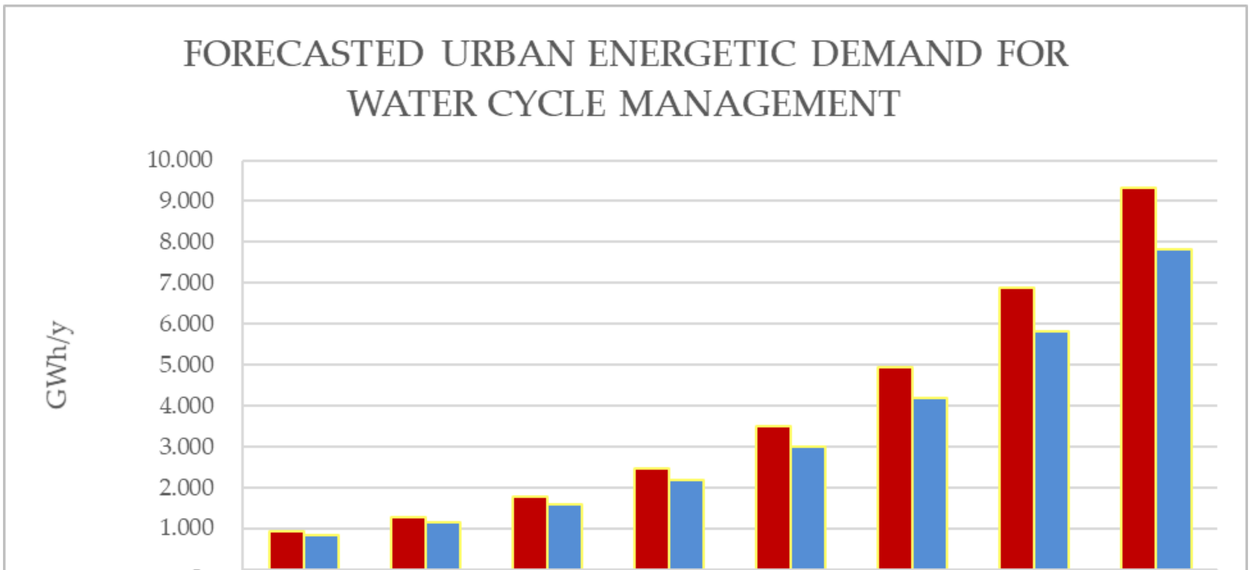
Data type	Size class	2015	2020	2025	2030	2035
Number of Agglomerations	10 million or more	0	0	0	1	1
Population	10 million or more	0	0	0	10789	13383
Number of Agglomerations	5 to 10 million	1	1	1	0	0
Population	5 to 10 million	5116	6702	8562	0	0
Number of Agglomerations	1 to 5 million	0	1	1	2	3
Population	1 to 5 million	0	1120	1447	2923	4736
Number of Agglomerations	500 000 to 1 million	2	2	4	6	8
Population	500 000 to 1 million	1407	1271	2673	4076	5699
Number of Agglomerations	300 000 to 500 000	3	4	9	10	9
Population	300 000 to 500 000	1228	1568	3451	3901	3796
Percentage of Urban Population	Fewer than 300 000	55%	52%	43%	39%	37%
Resulting Supply leakage VARIATION			3,03%	4,29%	9,10%	8,97%

Such computations are needed to forecast the water and consequent energetic demand for domestic consumption up to 2050 (fig 61 and fig 62).



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	0,92	1,28	1,78	2,51	3,62	5,19	7,33	10,00
HC DEMAND	0,64	0,89	1,24	1,75	2,51	3,61	5,10	5,44

Fig 61 Forecasted urban water demand



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	924	1.285	1.772	2.465	3.484	4.930	6.890	9.341
HC DEMAND	833	1.154	1.580	2.166	3.011	4.200	5.808	7.830

Fig 62 Forecasted urban energetic demand for water cycle management

Fig. 62 verifies how total water withdrawal from human activities, industrial, agricultural, and domestic, checks against the available renewable resource in United

Republic of Tanzania. The yellow line represents a cap set at 70% of the total value due to seasonality and the potential inaccessibility of the resource.

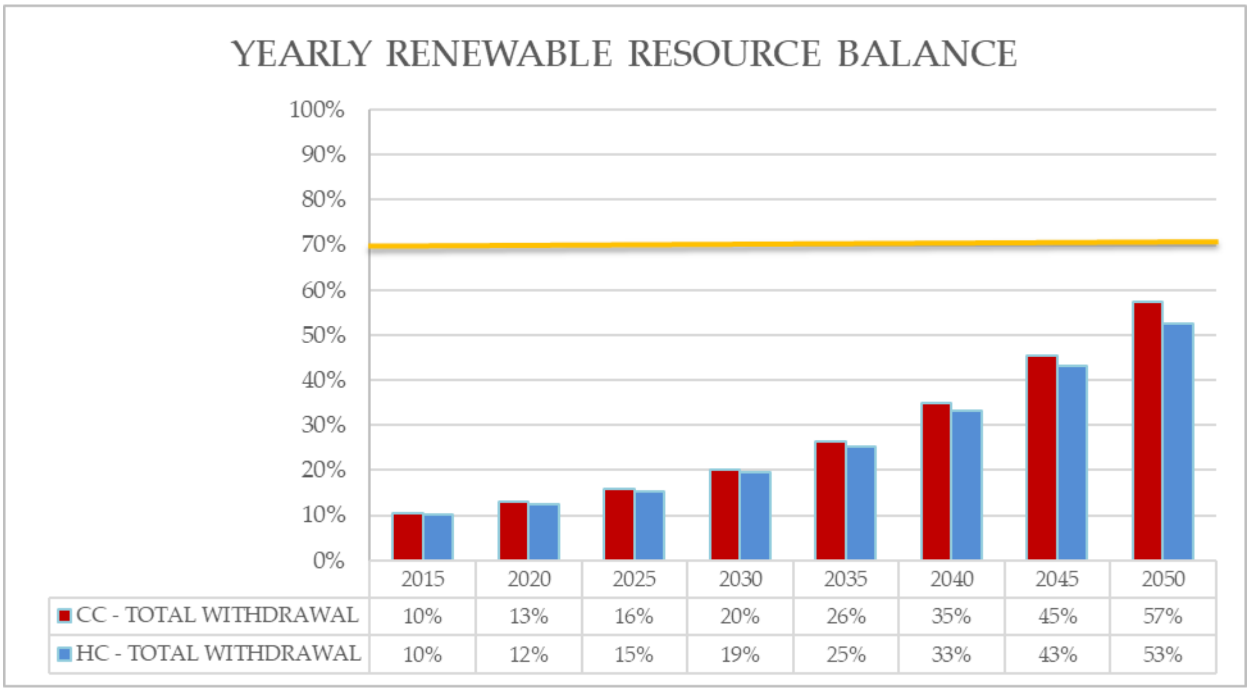


Fig 63 Yearly renewable resource balance

The 2015-2050 total estimated resources lost are highlighted in fig. 64

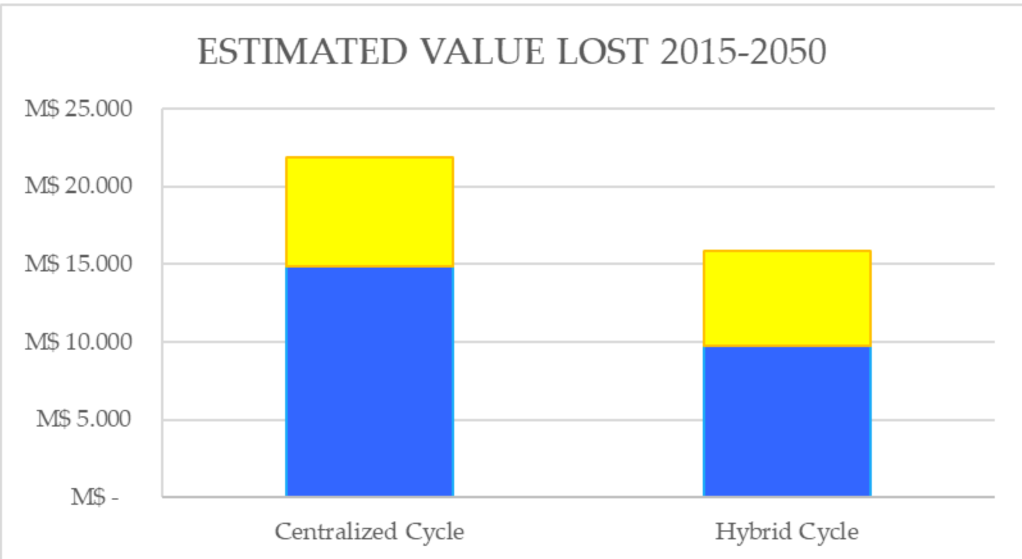


Fig 64 Estimated value lost 2015-2050

EUROPE

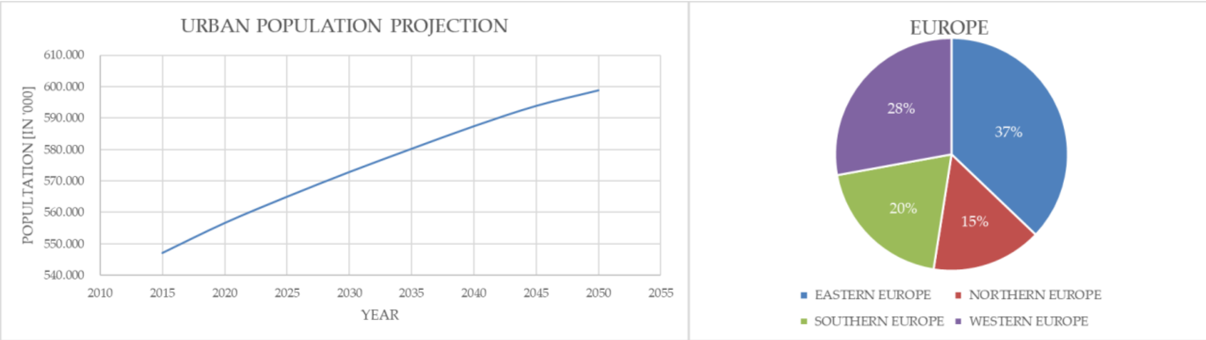
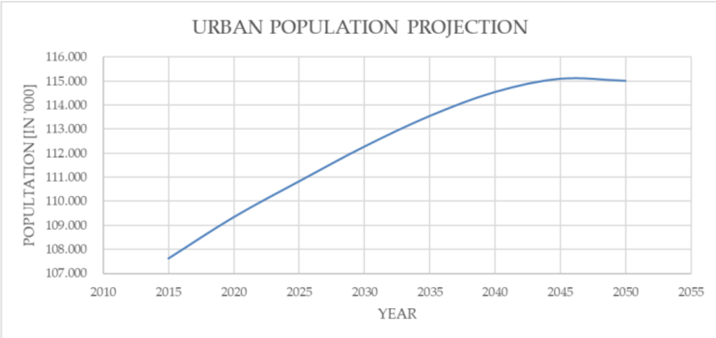


fig. 65 – Urban Population Projection

table 40 – Model Results

EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	1,16
min WATER price Growth rate for NPV>=0		-6%
min ENERGY PRICE for NPV>=0	$	-0,97
min ENERGY price Growth rate for NPV>=0		-155%
min 9m3/day treatment unit price	$	80.882
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		21,77
avg actual domestic demand 2015-2050 HC [km3/year]		15,12
DELTA		-31%
avg actual energy demand in CC [GWh/year]		27.639
avg actual energy demand in HC [GWh/year]		25.333
DELTA		-8%
PV of water lost in CC	M$	-1.472.710
PV of water lost in HC	M$	-1.022.797
PV of water savings with HC in 35years	M$	449.912
PV of energy consumed in CC	M$	147.177
PV of energy consumed in HC	M$	132.152
PV of energy expenditure if adoptiong HC for next 35years	M$	-15.025
WATER STRESS LEVEL(% of renewable resource used)		37%

SOUTHERN EUROPE



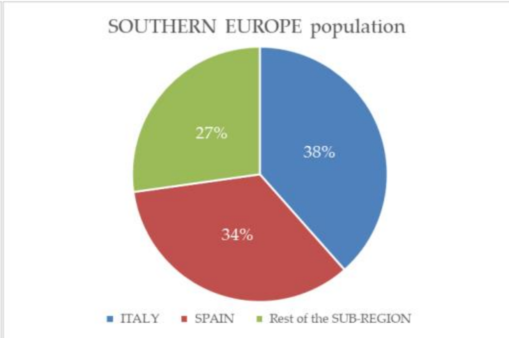


fig. 66 – Urban Population Projection

table 41 – Model Results

SOUTHERN EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	0,98
min WATER price Growth rate for NPV>=0		-15%
min ENERGY PRICE for NPV>=0	$	-3,43
min ENERGY price Growth rate for NPV>=0		-261%
min 9m3/day treatment unit price	$	130.058
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		22,68
avg actual domestic demand 2015-2050 HC [km3/year]		15,77
DELTA		-30%
avg actual energy demand in CC [GWh/year]		28.433
avg actual energy demand in HC [GWh/year]		25.186
DELTA		-11%
PV of water lost in CC	M$	-697.419
PV of water lost in HC	M$	-484.784
PV of water savings with HC in 35years	M$	212.635
PV of energy consumed in CC	M$	73.179
PV of energy consumed in HC	M$	64.987
PV of energy expenditure if adoptiong HC for next 35years	M$	-8.192
WATER STRESS LEVEL(% of renewable resource used)		128%

ITALY - SOUTHERN EUROPE

At a Glance

Fig. 67 illustrates the projected change in population in United Republic of Tanzania, while table 42 summarizes the main outputs of the model.

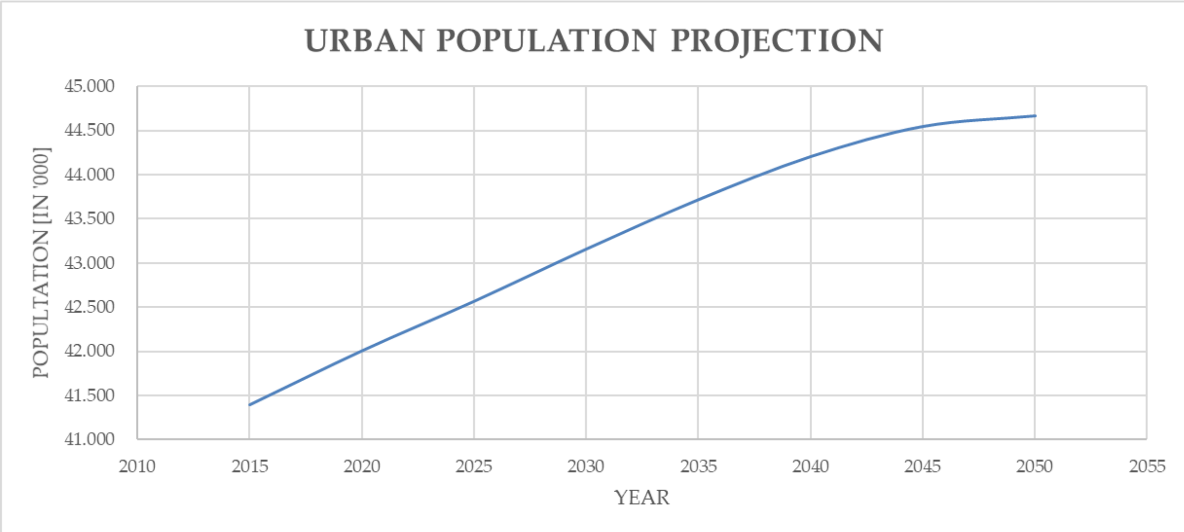


fig. 67 – Urban Population Projection

table 42 – Model Results

ITALY RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,76
min WATER price Growth rate for NPV>=0		-22%
min ENERGY PRICE for NPV>=0	$	-5,65
min ENERGY price Growth rate for NPV>=0		-269%
min 9m3/day treatment unit price	$	189.617
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		10,20
avg actual domestic demand 2015-2050 HC [km^3/year]		7,09
DELTA		-31%
avg actual energy demand in CC [GWh/year]		10.149
avg actual energy demand in HC [GWh/year]		9.035
DELTA		-11%
PV of water lost in CC	M$	-443.778
PV of water lost in HC	M$	-308.456
PV of water savings with HC in 35years	M$	135.322
PV of energy consumed in CC	M$	39.842
PV of energy consumed in HC	M$	35.469
PV of energy expenditure if adoptiong HC for next 35years	M$	-4.373
WATER STRESS LEVEL(% of renewable water resource used)		107%

PHASE 1

Figures 68 and 69 respectively show the results from the first phase of the model:

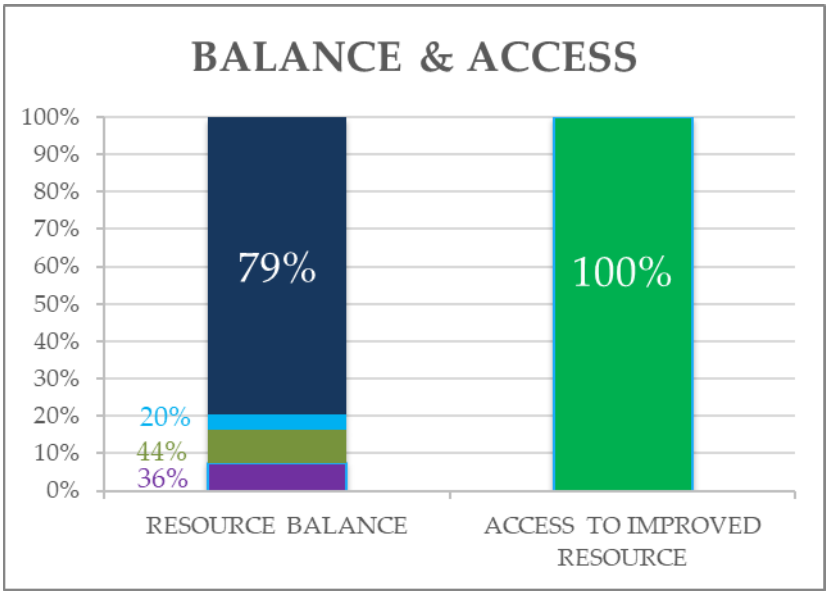


Fig. 68 - On the left, total yearly renewable water available(dark blue, absolute percentage), withdrawal for domestic use(light blue), for agricultural use(green), and industrial use(purple) and respective relative percentages with respect to the total withdrawn; On the right the percentage of the urban population with access to improved water sources.

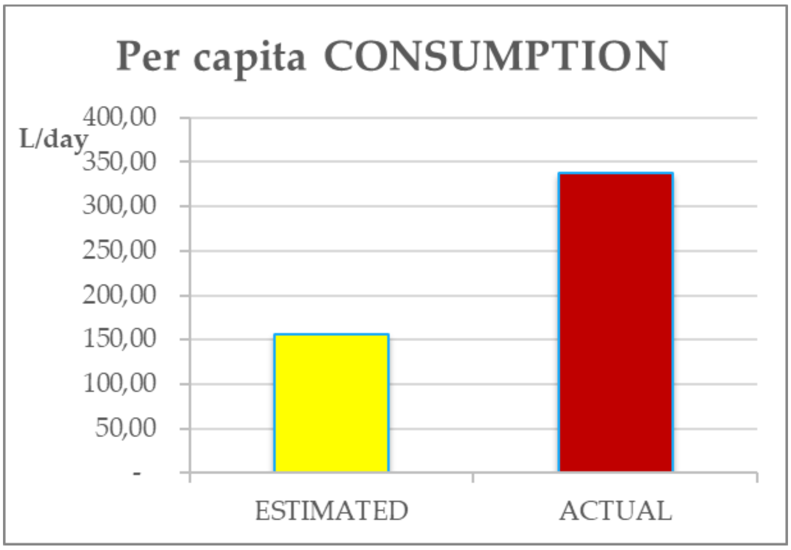


Fig. 69 - Graphic comparison between estimated and actual per capita consumption;

PHASE 2

In order to satisfy this consumer demand, the water and electric energy requirements vary depending on the typology of the urban hydrologic cycle.

Figures 70 and 71 respectively compare these aspects:

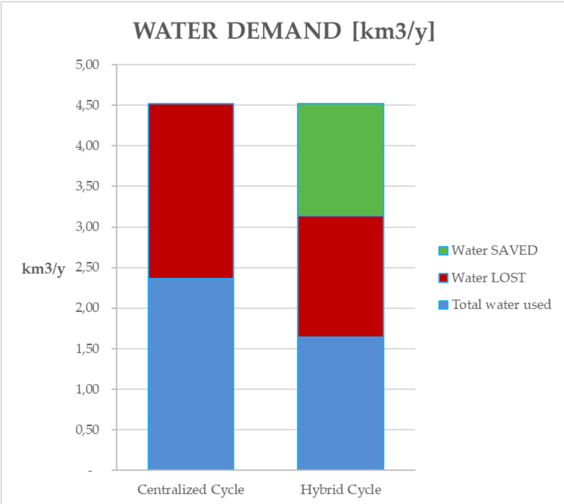


Fig. 70 WATER demand

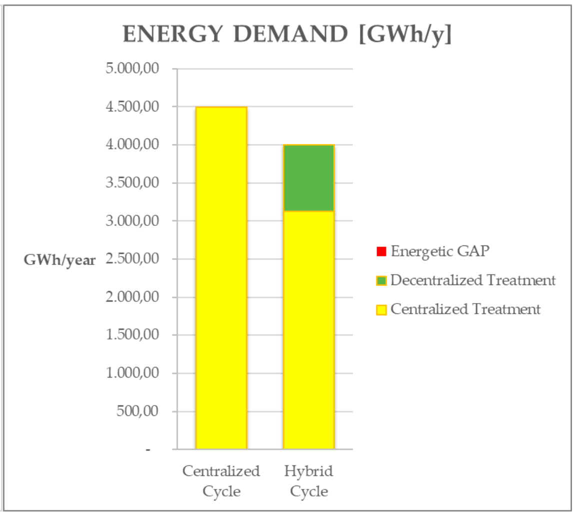


Fig. 71 ENERGY demand

Consumption divides the energetic requirements in two macro stages, upstream and downstream. Table 43 computes the impact of a relative increase in energetic efficiency.

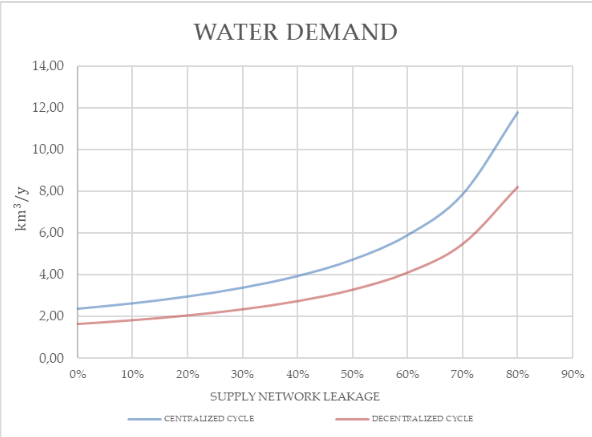
Table 43 in both quantitative figures and percentages for easier comparison

Total ENERGY demand in CC [GWh/year]		**Raw water treatment & distribution**						
		0,85	**0,90**	**0,95**	**1,00**	**1,05**	**1,10**	**1,15**
Collection & treatment	**0,85**	3.821	4.002	4.183	4.365	4.546	4.727	4.908
	0,90	3.865	4.046	4.227	4.408	4.589	4.771	4.952
	0,95	3.909	4.090	4.271	4.452	4.633	4.814	4.995
	1,00	3.952	4.133	4.314	4.496	4.677	4.858	5.039
	1,05	3.996	4.177	4.358	4.539	4.720	4.901	5.083
	1,10	4.039	4.221	4.402	4.583	4.764	4.945	5.126
	1,15	4.083	4.264	4.445	4.627	4.808	4.989	5.170

Values in %

Total ENERGY demand in CC [GWh/year]		**Raw water treatment & distribution**						
		85%	**90%**	**95%**	**100%**	**105%**	**110%**	**115%**
Collection & treatment	**85%**	-15%	-11%	-7%	-3%	1%	5%	9%
	90%	-14%	-10%	-6%	-2%	2%	6%	10%
	95%	-13%	-9%	-5%	-1%	3%	7%	11%
	100%	-12%	-8%	-4%	0%	4%	8%	12%
	105%	-11%	-7%	-3%	1%	5%	9%	13%
	110%	-10%	-6%	-2%	2%	6%	10%	14%
	115%	-9%	-5%	-1%	3%	7%	11%	15%

In this case, it appears clear that the up-stream energetic consumption has a more significant impact on the total efficiency of the process, therefore, implying that the majority of investments should be targeting improvement in these stages. The reality is that most energy-intensive functions in the upstream stages require lifting water; hence there are physical barriers under which consumptions cannot fall. Because of this issue, figures 72 and figure 73 plot the variation of water and energy demand as a function of the state of deterioration of the infrastructure represented by the leakage percentage.



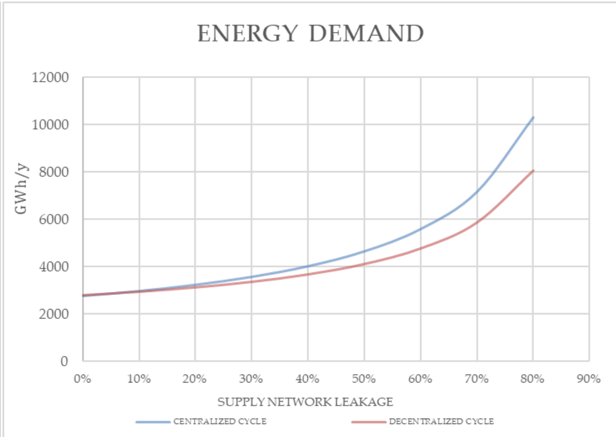


Fig. 72 & Fig. 73 Water and Energy demand as a function of both cycle type and infrastructural deterioration

Because of this, decentralized treatment performances need to be compared not only to centralized wastewater treatment but, more importantly, with the upstream energetic expenditure. Hence fig. 74 compares the effective energetic cost of upstream procurement and supply, net of the network losses, with the decentralized treatment consumption. When the former is higher than the latter, from a resource standpoint, the hybrid cycle adoption is a GO.

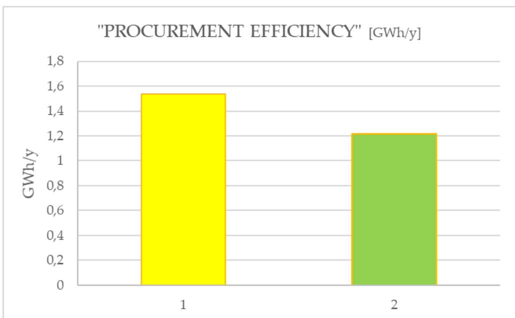


Fig. 74 Procurement efficiency; is water saved through greywater reuse more efficient than the process of procuring fresh water from traditional sources?

Whether this is the case or not, the financial analysis will have the last say.

PHASE 3

In Italy the cost of water and energy are respectively 2,88 $ /m3 and 0,26 $/kWh. In the base case scenario, the hypothesis was to keep at zero both the energy and water growth rates. Furthermore, the discount rate is initially considered zero; taking these factors into account, the present value of the combined savings over 15 years is depicted in fig 75 while the project's NPV per household for both STATE and INDEPENDENT implementation in fig 76.

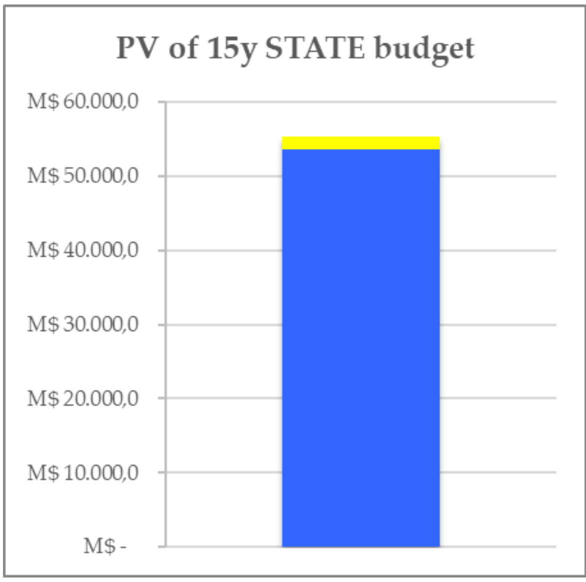


Fig. 75 PV of savings over 15 years

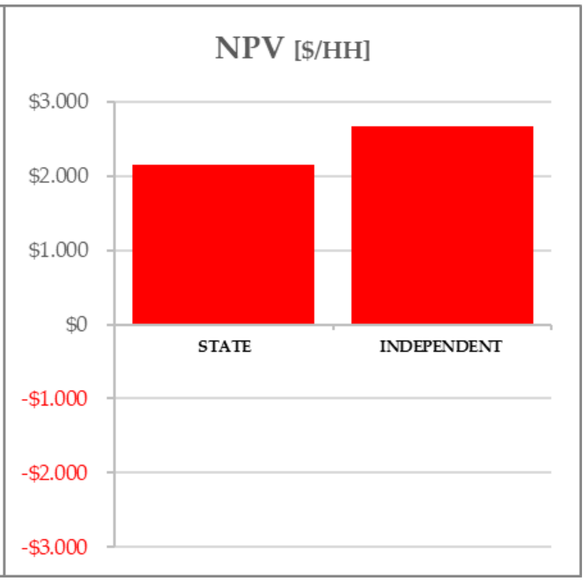


Fig. 76 NPV for a single household

The sensitivity analysis, performed with the help of tables 44 (water-energy cost), describes the combined value of savings depending on the cost of the resources.

Table 44 Total yearly savings[M$] (State POV)

Total yearly SAVINGS (STATE) [M$/y]		Cost of WATER [$/m³]						
		2,47	2,60	2,74	2,88	3,02	3,18	3,33
Cost of ENERGY [$/kWh]	0,22	M$ 3.160	M$ 3.321	M$ 3.491	M$ 3.669	M$ 3.848	M$ 4.035	M$ 4.232
	0,23	M$ 3.165	M$ 3.326	M$ 3.496	M$ 3.675	M$ 3.853	M$ 4.041	M$ 4.237
	0,25	M$ 3.171	M$ 3.332	M$ 3.502	M$ 3.680	M$ 3.859	M$ 4.046	M$ 4.243
	0,26	M$ 3.177	M$ 3.338	M$ 3.507	M$ 3.686	M$ 3.864	M$ 4.052	M$ 4.249
	0,27	M$ 3.182	M$ 3.343	M$ 3.513	M$ 3.692	M$ 3.870	M$ 4.058	M$ 4.254
	0,29	M$ 3.188	M$ 3.350	M$ 3.519	M$ 3.698	M$ 3.876	M$ 4.064	M$ 4.260
	0,30	M$ 3.195	M$ 3.356	M$ 3.525	M$ 3.704	M$ 3.883	M$ 4.070	M$ 4.267

Because of positive NPV, the following data tables will analyze the 5-year plan carried out with State grants, which is the most challenging due to its short payback period. The independent variables taken into account are the cost of the resources and their respective annual growth rates.

Table 45 dependent variable, 5y project NPV ; independent variables: Cost of WATER, Cost of ENERGY

5y project NPV (STATE)		Cost of WATER [$\$/m^3$]						
		2,47	2,89	3,31	3,74	4,16	4,58	5,00
Cost of ENERGY [$/kWh]	0,22	M$ 5.771	M$ 8.387	M$ 11.002	M$ 13.618	M$ 16.233	M$ 18.849	M$ 21.464
	0,23	M$ 5.797	M$ 8.413	M$ 11.028	M$ 13.644	M$ 16.259	M$ 18.875	M$ 21.490
	0,25	M$ 5.824	M$ 8.440	M$ 11.056	M$ 13.671	M$ 16.287	M$ 18.902	M$ 21.518
	0,26	M$ 5.853	M$ 8.469	M$ 11.084	M$ 13.700	M$ 16.316	M$ 18.931	M$ 21.547
	0,27	M$ 5.882	M$ 8.498	M$ 11.113	M$ 13.729	M$ 16.344	M$ 18.960	M$ 21.576
	0,29	M$ 5.912	M$ 8.528	M$ 11.144	M$ 13.759	M$ 16.375	M$ 18.990	M$ 21.606
	0,30	M$ 5.944	M$ 8.560	M$ 11.175	M$ 13.791	M$ 16.406	M$ 19.022	M$ 21.638

Table 46 dependent variable, 5y project NPV ; independent variables: Cost of WATER & Growth Rate

5y project NPV (STATE)		Cost of WATER [$\$/m^3$]						
		2,47	2,89	3,31	3,74	4,16	4,58	5,00
Cost of WATER growth rate	0,00	M$ 5.853	M$ 8.469	M$ 11.084	M$ 13.700	M$ 16.316	M$ 18.931	M$ 21.547
	-0,04	M$ 4.521	M$ 6.908	M$ 9.296	M$ 11.684	M$ 14.072	M$ 16.460	M$ 18.847
	-0,07	M$ 3.301	M$ 5.480	M$ 7.659	M$ 9.839	M$ 12.018	M$ 14.198	M$ 16.377
	-0,11	M$ 2.186	M$ 4.175	M$ 6.163	M$ 8.152	M$ 10.141	M$ 12.130	M$ 14.119
	-0,15	M$ 1.168	M$ 2.983	M$ 4.797	M$ 6.612	M$ 8.427	M$ 10.242	M$ 12.057
	-0,18	M$ 239	M$ 1.896	M$ 3.552	M$ 5.208	M$ 6.864	M$ 8.521	M$ 10.177
	-0,22	M$ -606	M$ 905	M$ 2.417	M$ 3.929	M$ 5.441	M$ 6.952	M$ 8.464

Table 47 dependent variable, 5y project NPV ; independent variables: Cost of ENERGY & Growth Rate

5y project NPV (STATE)		Cost of ENERGY [$/kWh]						
		0,22	0,23	0,25	0,26	0,27	0,29	0,30
Cost of ENERGY growth rate	0%	M$ 8.317	M$ 8.343	M$ 8.371	M$ 8.400	M$ 8.428	M$ 8.459	M$ 8.490
	-45%	M$ 7.985	M$ 7.994	M$ 8.003	M$ 8.012	M$ 8.022	M$ 8.032	M$ 8.042
	-90%	M$ 7.884	M$ 7.887	M$ 7.890	M$ 7.894	M$ 7.898	M$ 7.901	M$ 7.905
	-134%	M$ 7.847	M$ 7.848	M$ 7.850	M$ 7.851	M$ 7.853	M$ 7.854	M$ 7.856
	-179%	M$ 7.830	M$ 7.831	M$ 7.831	M$ 7.832	M$ 7.832	M$ 7.833	M$ 7.833
	-224%	M$ 7.802	M$ 7.801	M$ 7.800	M$ 7.799	M$ 7.798	M$ 7.796	M$ 7.795
	-269%	M$ 7.638	M$ 7.628	M$ 7.617	M$ 7.607	M$ 7.596	M$ 7.585	M$ 7.573

An important variable to consider is the cost of the treatment unit. A differently priced technology could result in other scenarios. We now take this angle by analyzing the effects of varying the cost of the differently sized and priced unit in the case of independent implementation. Tables 48 and 49 tackle the same problem by considering the initial cost variation of the treatment unit with a 3m³/day and 1m³/day of water treated in light of the changing cost of water during a 15y plan.

Table 48 dependent variable, 15y project NPV ; independent variables: Cost of WATER, Cost of 9m³ treatment unit

15y project NPV (INDEPENDENT)		Cost of WATER [$/m³]						
		2,47	2,60	2,74	2,88	3,02	3,18	3,33
3m³ Treatment UNIT $	$ 7.270	M$ 9.971	M$ 12.047	M$ 14.232	M$ 16.531	M$ 18.831	M$ 21.246	M$ 23.781
	$ 8.580	M$ 8.530	M$ 10.606	M$ 12.791	M$ 15.090	M$ 17.390	M$ 19.805	M$ 22.340
	$ 9.890	M$ 7.089	M$ 9.165	M$ 11.350	M$ 13.649	M$ 15.949	M$ 18.364	M$ 20.899
	$ 11.200	M$ 5.648	M$ 7.724	M$ 9.909	M$ 12.208	M$ 14.508	M$ 16.923	M$ 19.458
	$ 12.510	M$ 4.207	M$ 6.283	M$ 8.468	M$ 10.767	M$ 13.067	M$ 15.482	M$ 18.017
	$ 13.820	M$ 2.766	M$ 4.842	M$ 7.027	M$ 9.326	M$ 11.626	M$ 14.041	M$ 16.576
	$ 15.130	M$ 1.325	M$ 3.401	M$ 5.586	M$ 7.885	M$ 10.185	M$ 12.600	M$ 15.135

Table 49 dependent variable, 15y project NPV ; independent variables: Cost of ENERGY, Cost of 9m³ treatment unit

15y project NPV (INDEPENDENT)		Cost of WATER [$/m³]						
		2,47	2,60	2,74	2,88	3,02	3,18	3,33
1m³ Treatment UNIT $	$ 4.070	M$ -8.921	M$ -8.229	M$ -7.501	M$ -6.734	M$ -5.968	M$ -5.163	M$ -4.318
	$ 5.380	M$ -10.362	M$ -9.670	M$ -8.942	M$ -8.175	M$ -7.409	M$ -6.604	M$ -5.759
	$ 6.690	M$ -11.803	M$ -11.111	M$ -10.383	M$ -9.616	M$ -8.850	M$ -8.045	M$ -7.200
	$ 8.000	M$ -13.244	M$ -12.552	M$ -11.824	M$ -11.057	M$ -10.291	M$ -9.486	M$ -8.641
	$ 9.310	M$ -14.685	M$ -13.993	M$ -13.265	M$ -12.498	M$ -11.732	M$ -10.927	M$ -10.082
	$ 10.620	M$ -16.126	M$ -15.434	M$ -14.706	M$ -13.939	M$ -13.173	M$ -12.368	M$ -11.523
	$ 11.930	M$ -17.567	M$ -16.875	M$ -16.147	M$ -15.380	M$ -14.614	M$ -13.809	M$ -12.964

Based on these figures we can conclude that Italy definitely has the figures to render these initiatives other than environmentally sustainable, financially profitable. To further grasp the environmental impact of this solution, section 4 will analyze the likely future situation.

PHASE 4

In terms of actual city size and urban development forecast in Italy, table 50 summarizes the situation while fig 77 provides a graphic representation on the hypothesis made to quantify the magnitude of the infrastructural deterioration proportionally to the speed of city growth as a function of their size. The quadratic equation used in this simulation is set to hit a value of 20% of relative increase for the rise of a new city of 10 million inhabitants.

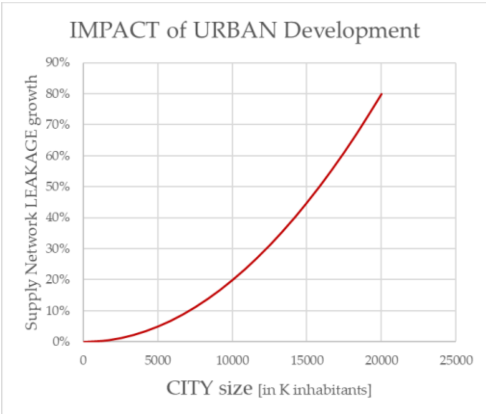
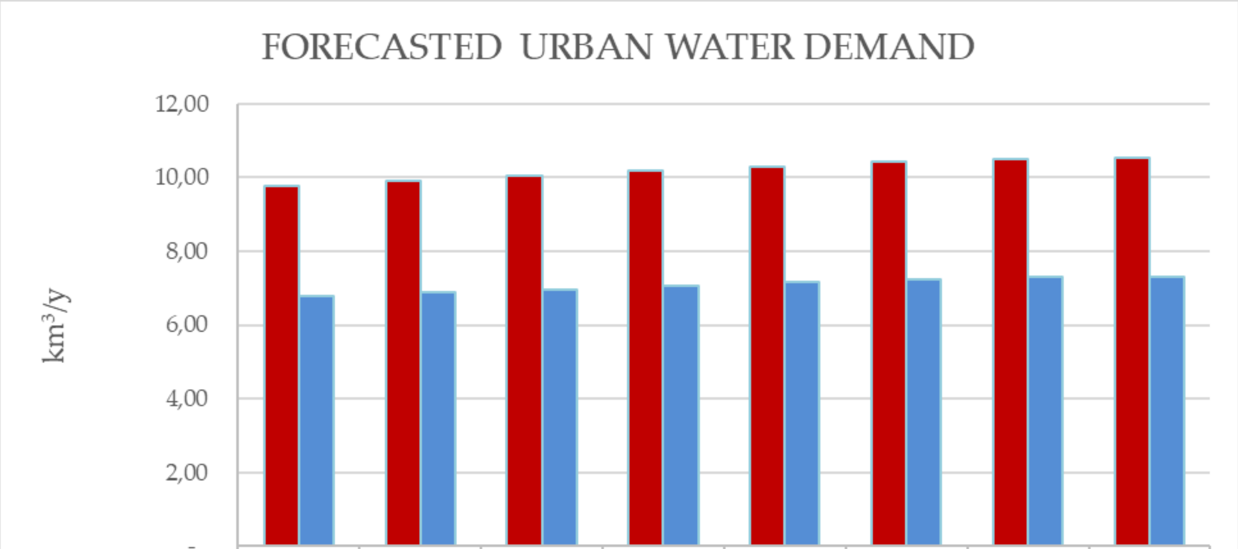


Fig. 77 *Infrastructural deterioration as a function of city size*

Table 50 *Forecasted city size growth and resulting infrastructural deterioration*

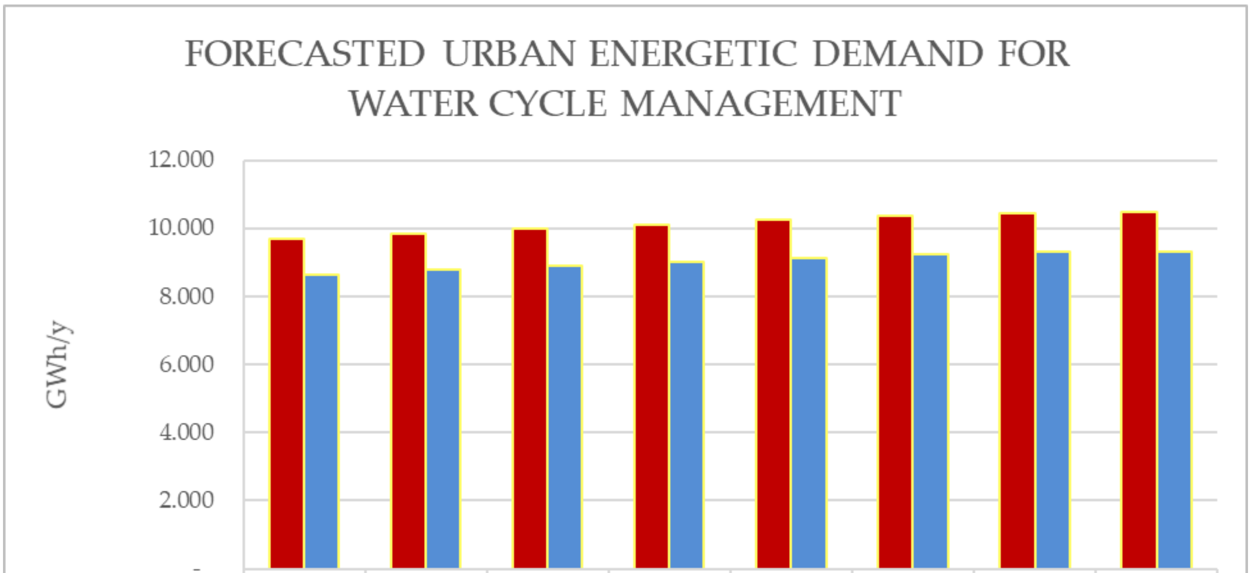
Data type	Size class	2015	2020	2025	2030	2035
Number of Agglomerations	10 million or more	0	0	0	0	0
Population	10 million or more	0	0	0	0	0
Number of Agglomerations	5 to 10 million	0	0	0	0	0
Population	5 to 10 million	0	0	0	0	0
Number of Agglomerations	1 to 5 million	4	4	4	4	4
Population	1 to 5 million	11188	11376	11507	11663	11815
Number of Agglomerations	500 000 to 1 million	12	12	12	14	14
Population	500 000 to 1 million	8188	8370	8491	9616	9741
Number of Agglomerations	300 000 to 500 000	15	16	17	16	16
Population	300 000 to 500 000	5803	6299	6735	6134	6215
Percentage of Urban Population	Fewer than 300 000	39%	38%	37%	36%	36%
Resulting Supply leakage VARIATION			0,0%	0,0%	0,0%	0,0%

Such computations are needed to forecast the water and consequent energetic demand for domestic consumption up to 2050 (fig 78 and fig 79).



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	9,76	9,90	10,04	10,18	10,31	10,42	10,50	10,53
HC DEMAND	6,78	6,89	6,98	7,07	7,17	7,25	7,30	7,30

Fig 78 Forecasted urban water demand



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	9.707	9.850	9.981	10.119	10.250	10.365	10.444	10.472
HC DEMAND	8.642	8.769	8.886	9.009	9.125	9.226	9.297	9.322

Fig 79 Forecasted urban energetic demand for water cycle management

Figure 80 verifies how total water withdrawal from human activities, industrial, agricultural, and domestic, checks against the available renewable resource in United

Republic of Tanzania. The yellow line represents a cap set at 70% of the total value due to seasonality and the potential inaccessibility of the resource.

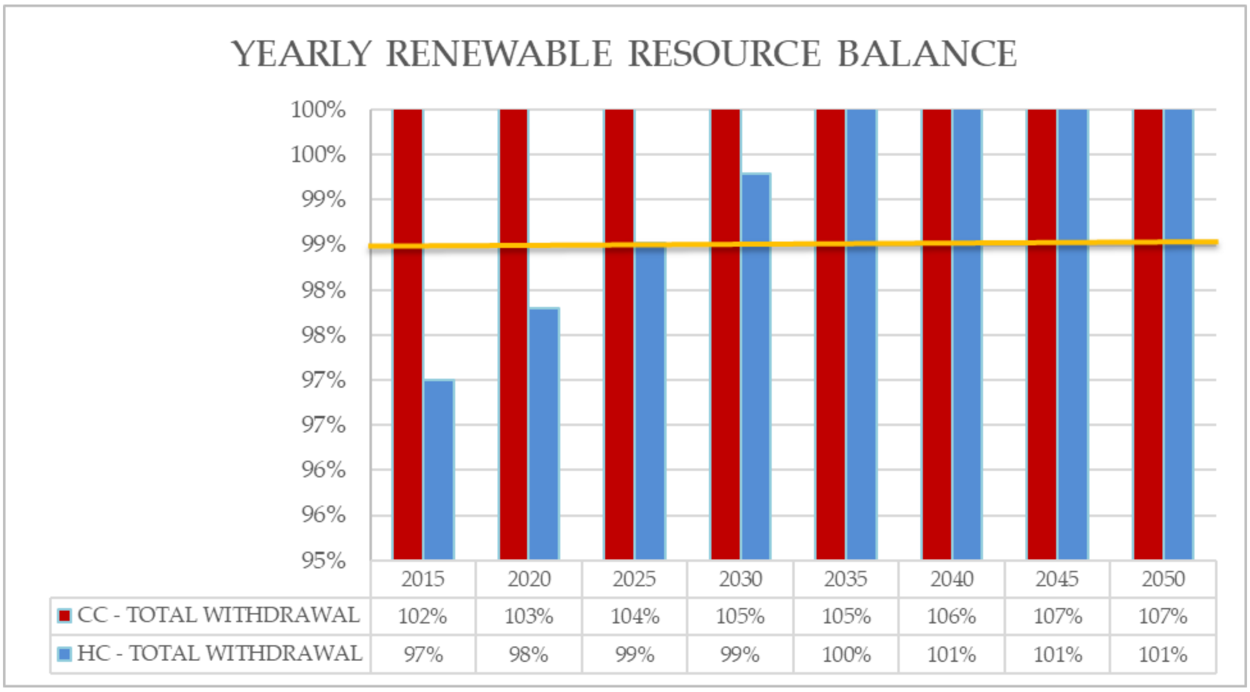


Fig 80 Yearly renewable resource balance

The 2015-2050 total estimated resources lost are highlighted in figure 81

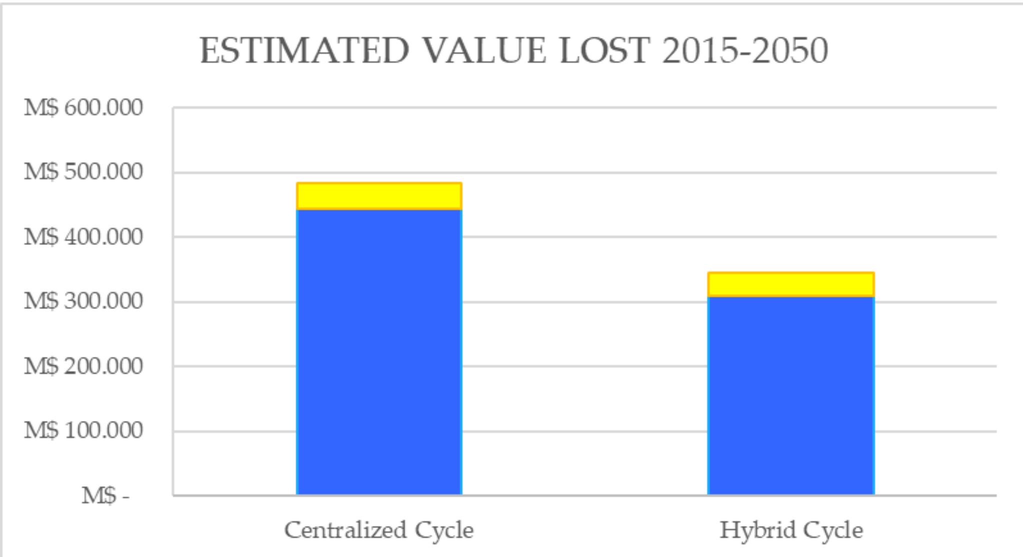


Fig 81 Estimated value lost 2015-2050

SPAIN - SOUTHERN EUROPE

At a Glance

Figure 82 illustrates the projected change in population in United Republic of Tanzania, while table 52 summarizes the main outputs of the model.

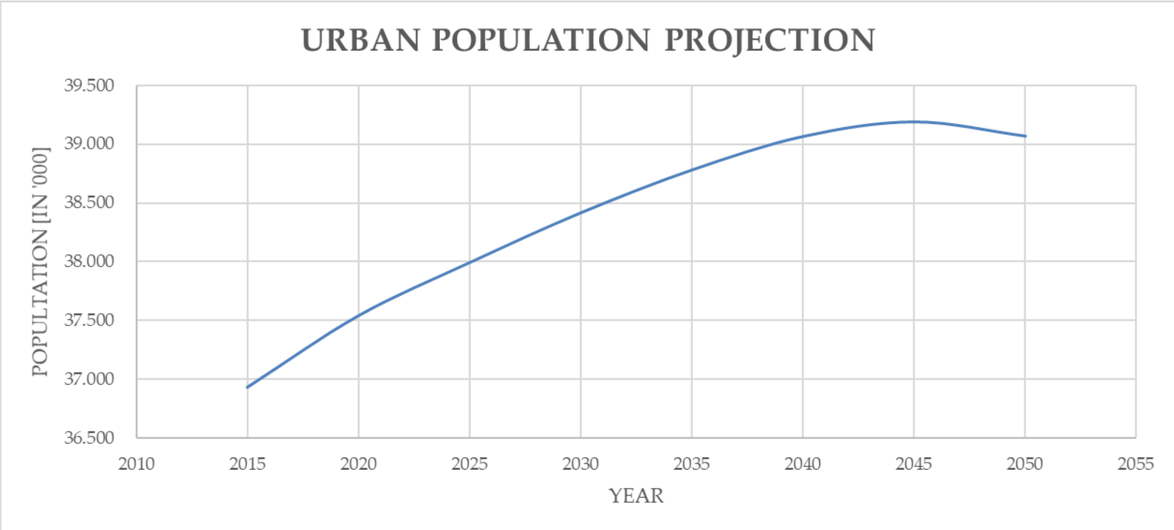


fig. 82 – Urban Population Projection

table 52

SPAIN RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,22
min WATER price Growth rate for NPV>=0		-7%
min ENERGY PRICE for NPV>=0	$	-0,94
min ENERGY price Growth rate for NPV>=0		-252%
min 9m3/day treatment unit price	$	63.305
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		6,30
avg actual domestic demand 2015-2050 HC [km^3/year]		4,38
DELTA		-30%
avg actual energy demand in CC [GWh/year]		10.546
avg actual energy demand in HC [GWh/year]		9.297
DELTA		-12%
PV of water lost in CC	M$	-63.824
PV of water lost in HC	M$	-44.384
PV of water savings with HC in 35years	M$	19.439
PV of energy consumed in CC	M$	13.420
PV of energy consumed in HC	M$	11.831
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.589
WATER STRESS LEVEL(% of renewable water resource used)		72%

PHASE 1

Figures 83 and 84 respectively show the results from the first phase of the model:

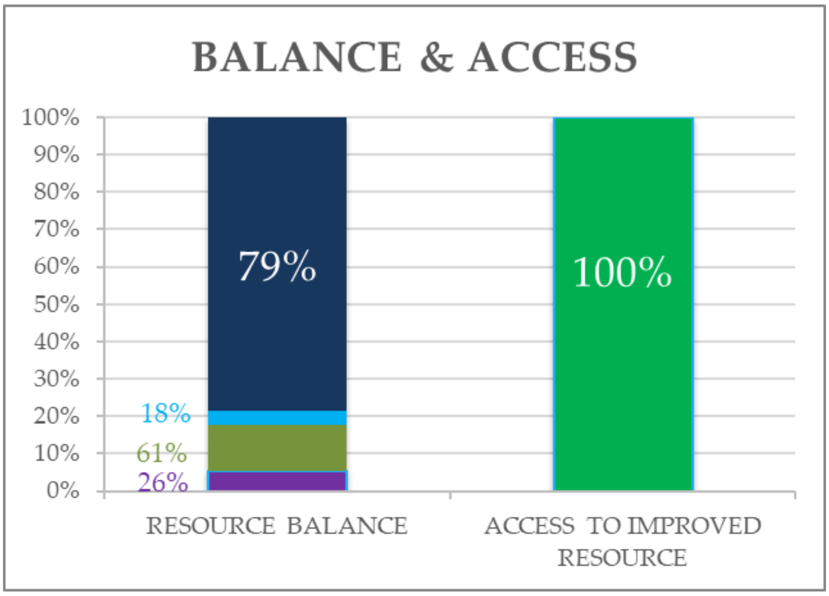


Fig. 83 - On the left, total yearly renewable water available(dark blue, absolute percentage), withdrawal for domestic use(light blue), for agricultural use(green), and industrial use(purple) and respective relative percentages with respect to the total withdrawn; On the right the percentage of the urban population with access to improved water sources.

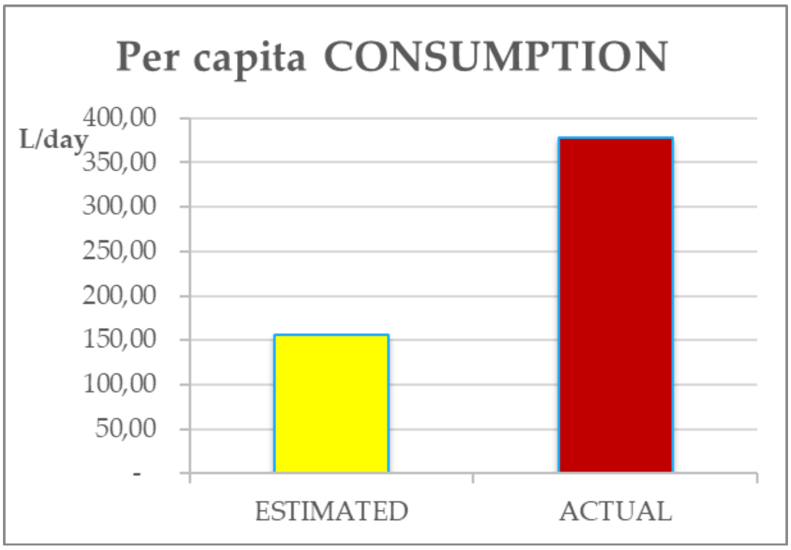


Fig. 84 - Graphic comparison between estimated and actual per capita consumption;

PHASE 2

In order to satisfy this consumer demand, the water and electric energy requirements vary depending on the typology of the urban hydrologic cycle.

Figures 85 and 86 respectively compare these aspects:

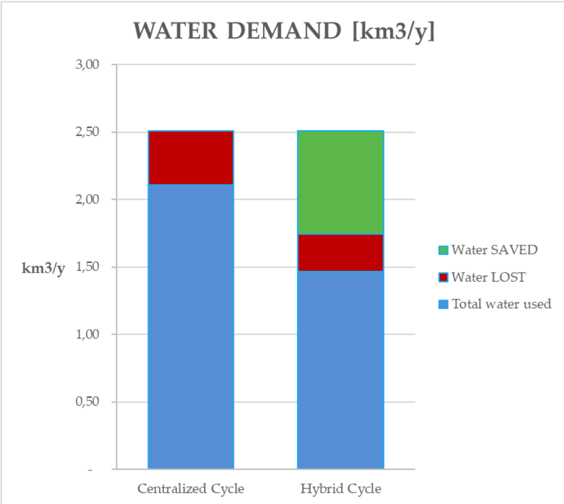


Fig. 85 WATER demand

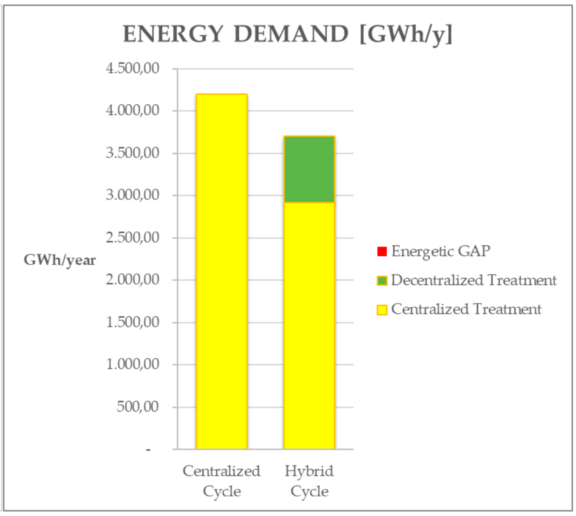


Fig. 86 ENERGY demand

Consumption divides the energetic requirements in two macro stages, upstream and downstream. Table 53 computes the impact of a relative increase in energetic efficiency.

Table 53 in both quantitative figures and percentages for easier comparison

Total ENERGY demand in CC [GWh/year]		Raw water treatment & distribution						
		0,85	0,90	0,95	1,00	1,05	1,10	1,15
Collection & treatment	0,85	3.567	3.718	3.868	4.019	4.170	4.320	4.471
	0,90	3.626	3.777	3.927	4.078	4.229	4.379	4.530
	0,95	3.685	3.836	3.986	4.137	4.288	4.438	4.589
	1,00	3.744	3.895	4.046	4.196	4.347	4.498	4.648
	1,05	3.803	3.954	4.105	4.255	4.406	4.557	4.707
	1,10	3.863	4.013	4.164	4.315	4.465	4.616	4.767
	1,15	3.922	4.072	4.223	4.374	4.524	4.675	4.826

Values in %

Total ENERGY demand in CC [GWh/year]		Raw water treatment & distribution						
		85%	90%	95%	100%	105%	110%	115%
Collection & treatment	85%	-15%	-11%	-8%	-4%	-1%	3%	7%
	90%	-14%	-10%	-6%	-3%	1%	4%	8%
	95%	-12%	-9%	-5%	-1%	2%	6%	9%
	100%	-11%	-7%	-4%	0%	4%	7%	11%
	105%	-9%	-6%	-2%	1%	5%	9%	12%
	110%	-8%	-4%	-1%	3%	6%	10%	14%
	115%	-7%	-3%	1%	4%	8%	11%	15%

In this case, it appears clear that the up-stream energetic consumption has a more significant impact on the total efficiency of the process, therefore, implying that the majority of investments should be targeting improvement in these stages. The reality is that most energy-intensive functions in the upstream stages require lifting water; hence there are physical barriers under which consumptions cannot fall. Because of this issue, figure 87 and figure 88 plot the variation of water and energy demand as a function of the state of deterioration of the infrastructure represented by the leakage percentage.

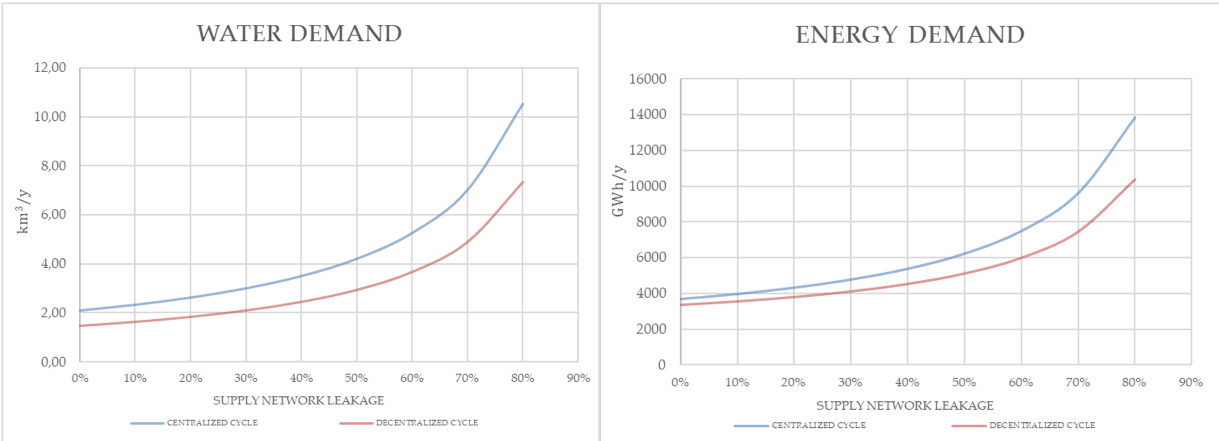


Fig. 87 & Fig. 88 Water and Energy demand as a function of both cycle type and infrastructural deterioration

Because of this, decentralized treatment performances need to be compared not only to centralized wastewater treatment but, more importantly, with the upstream energetic expenditure. Hence figure 89 compares the effective energetic cost of upstream procurement and supply, net of the network losses, with the decentralized treatment consumption. When the former is higher than the latter, from a resource standpoint, the hybrid cycle adoption is a GO.

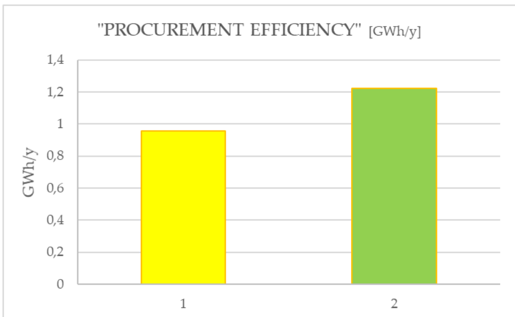


Fig. 89 Procurement efficiency; is water saved through greywater reuse more efficient than the process of procuring fresh water from traditional sources?

Whether this is the case or not, the financial analysis will have the last say.

PHASE 3

In Italy the cost of water and energy are respectively 2,88 $ /m3 and 0,26 $/kWh. In the base case scenario, the hypothesis was to keep at zero both the energy and water growth rates. Furthermore, the discount rate is initially considered zero; taking these factors into account, the present value of the combined savings over 15 years is depicted in fig 90 while the project's NPV per household for both STATE and INDEPENDENT implementation in fig 91.

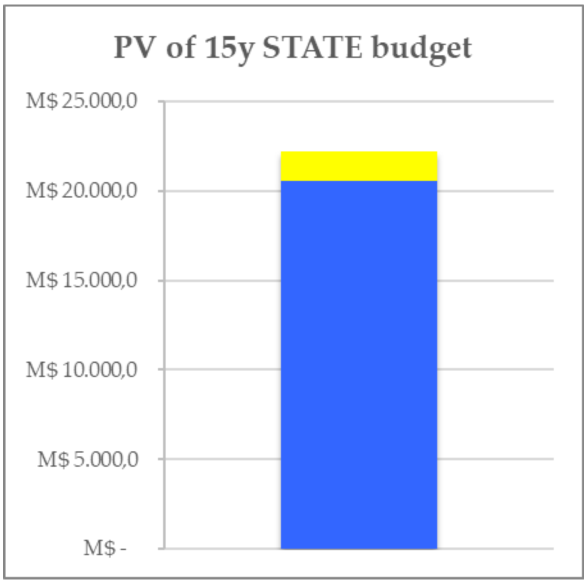


Fig. 90 PV of savings over 15 years

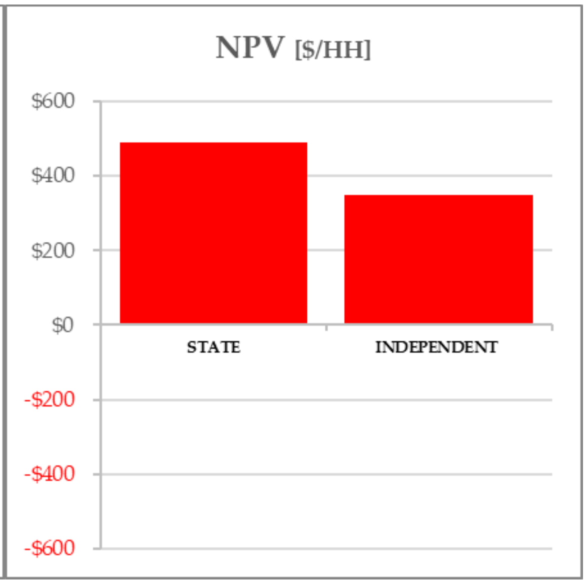


Fig. 91 NPV for a single household

The sensitivity analysis, performed with the help of tables 54 (water-energy cost), describes the combined value of savings depending on the cost of the resources.

Table 54 Total yearly savings[M$] (State POV)

Total yearly SAVINGS (STATE) [M$/y]		Cost of WATER [$/m^3]						
		1,71	1,80	1,89	1,99	2,09	2,19	2,30
Cost of ENERGY [$/kWh]	0,21	M$ 1.269	M$ 1.330	M$ 1.395	M$ 1.464	M$ 1.532	M$ 1.604	M$ 1.679
	0,23	M$ 1.274	M$ 1.335	M$ 1.400	M$ 1.469	M$ 1.537	M$ 1.609	M$ 1.684
	0,24	M$ 1.279	M$ 1.341	M$ 1.406	M$ 1.474	M$ 1.542	M$ 1.614	M$ 1.690
	0,25	M$ 1.284	M$ 1.346	M$ 1.411	M$ 1.480	M$ 1.548	M$ 1.620	M$ 1.695
	0,26	M$ 1.290	M$ 1.352	M$ 1.417	M$ 1.485	M$ 1.554	M$ 1.625	M$ 1.701
	0,28	M$ 1.296	M$ 1.358	M$ 1.423	M$ 1.491	M$ 1.559	M$ 1.631	M$ 1.707
	0,29	M$ 1.302	M$ 1.364	M$ 1.429	M$ 1.497	M$ 1.566	M$ 1.637	M$ 1.713

Because of positive NPV, the following data tables will analyze the 5-year plan carried out with State grants, which is the most challenging due to its short payback period. The independent variables taken into account are the cost of the resources and their respective annual growth rates.

Table 55 dependent variable, 5y project NPV ; independent variables: Cost of WATER, Cost of ENERGY

5y project NPV (STATE)	Cost of WATER $[\$/m^3]$						
Cost of ENERGY [$/kWh]	1,71	2,00	2,29	2,58	2,87	3,16	3,46
0,21	M$ -2.606	M$ -1.604	M$ -602	M$ 400	M$ 1.402	M$ 2.404	M$ 3.406
0,23	M$ -2.581	M$ -1.579	M$ -577	M$ 425	M$ 1.427	M$ 2.429	M$ 3.432
0,24	M$ -2.554	M$ -1.552	M$ -550	M$ 452	M$ 1.454	M$ 2.456	M$ 3.458
0,25	M$ -2.527	M$ -1.524	M$ -522	M$ 480	M$ 1.482	M$ 2.484	M$ 3.486
0,26	M$ -2.499	M$ -1.497	M$ -494	M$ 508	M$ 1.510	M$ 2.512	M$ 3.514
0,28	M$ -2.469	M$ -1.467	M$ -465	M$ 537	M$ 1.539	M$ 2.541	M$ 3.543
0,29	M$ -2.439	M$ -1.436	M$ -434	M$ 568	M$ 1.570	M$ 2.572	M$ 3.574

Table 56 dependent variable, 5y project NPV ; independent variables: Cost of WATER & Growth Rate

5y project NPV (STATE)	Cost of WATER $[\$/m^3]$						
Cost of WATER growth rate	1,71	2,00	2,29	2,58	2,87	3,16	3,46
0,00	M$ -2.527	M$ -1.524	M$ -522	M$ 480	M$ 1.482	M$ 2.484	M$ 3.486
0,02	M$ -2.277	M$ -1.233	M$ -188	M$ 857	M$ 1.901	M$ 2.946	M$ 3.991
0,03	M$ -2.018	M$ -929	M$ 160	M$ 1.249	M$ 2.338	M$ 3.427	M$ 4.516
0,05	M$ -1.748	M$ -613	M$ 522	M$ 1.657	M$ 2.792	M$ 3.928	M$ 5.063
0,07	M$ -1.467	M$ -284	M$ 899	M$ 2.082	M$ 3.265	M$ 4.448	M$ 5.631
0,08	M$ -1.176	M$ 57	M$ 1.290	M$ 2.523	M$ 3.756	M$ 4.989	M$ 6.222
0,10	M$ -872	M$ 412	M$ 1.697	M$ 2.982	M$ 4.267	M$ 5.551	M$ 6.836

Table 57 dependent variable, 5y project NPV ; independent variables: Cost of ENERGY & Growth Rate

5y project NPV (STATE)	Cost of ENERGY [$/kWh]						
Cost of ENERGY growth rate	0,21	0,23	0,24	0,25	0,26	0,28	0,29
0%	M$ -1.631	M$ -1.605	M$ -1.579	M$ -1.551	M$ -1.523	M$ -1.494	M$ -1.463
2%	M$ -1.610	M$ -1.584	M$ -1.556	M$ -1.527	M$ -1.498	M$ -1.468	M$ -1.436
3%	M$ -1.589	M$ -1.562	M$ -1.533	M$ -1.503	M$ -1.472	M$ -1.440	M$ -1.407
5%	M$ -1.567	M$ -1.539	M$ -1.509	M$ -1.477	M$ -1.445	M$ -1.412	M$ -1.377
7%	M$ -1.544	M$ -1.514	M$ -1.483	M$ -1.450	M$ -1.417	M$ -1.383	M$ -1.346
8%	M$ -1.520	M$ -1.489	M$ -1.457	M$ -1.422	M$ -1.388	M$ -1.352	M$ -1.314
10%	M$ -1.496	M$ -1.463	M$ -1.429	M$ -1.394	M$ -1.358	M$ -1.320	M$ -1.281

An important variable to consider is the cost of the treatment unit. A differently priced technology could result in other scenarios. We now take this angle by analyzing the effects of varying the cost of the differently sized and priced unit in the case of independent implementation. Tables 58 and 59 tackle the same problem by considering the initial cost variation of the treatment unit with a 3m³/day and 1m³/day of water treated in light of the changing cost of water during a 15y plan.

Table 58 dependent variable, 15y project NPV ; independent variables: Cost of WATER, Cost of 9m³ treatment unit

15y project NPV (INDEPENDENT)		Cost of WATER [$/m³]						
		1,71	1,80	1,89	1,99	2,09	2,19	2,30
3m³ Treatment UNIT $	$ 7.270	M$ -2.020	M$ -586	M$ 924	M$ 2.513	M$ 4.102	M$ 5.770	M$ 7.522
	$ 8.580	M$ -3.461	M$ -2.027	M$ -517	M$ 1.072	M$ 2.661	M$ 4.329	M$ 6.081
	$ 9.890	M$ -4.902	M$ -3.468	M$ -1.958	M$ -369	M$ 1.220	M$ 2.888	M$ 4.640
	$ 11.200	M$ -6.343	M$ -4.909	M$ -3.399	M$ -1.810	M$ -221	M$ 1.447	M$ 3.199
	$ 12.510	M$ -7.784	M$ -6.350	M$ -4.840	M$ -3.251	M$ -1.662	M$ 6	M$ 1.758
	$ 13.820	M$ -9.225	M$ -7.791	M$ -6.281	M$ -4.692	M$ -3.103	M$ -1.435	M$ 317
	$ 15.130	M$ -10.666	M$ -9.232	M$ -7.722	M$ -6.133	M$ -4.544	M$ -2.876	M$ -1.124

Table 59 dependent variable, 15y project NPV ; independent variables: Cost of ENERGY, Cost of 9m³ treatment unit

15y project NPV (INDEPENDENT)		Cost of ENERGY [$/kWh]						
		0,21	0,23	0,24	0,25	0,26	0,28	0,29
3m³ Treatment UNIT $	$ 7.270	M$ 3.207	M$ 2.988	M$ 2.756	M$ 2.513	M$ 2.269	M$ 2.013	M$ 1.745
	$ 8.580	M$ 1.766	M$ 1.547	M$ 1.315	M$ 1.072	M$ 828	M$ 572	M$ 304
	$ 9.890	M$ 325	M$ 106	M$ -126	M$ -369	M$ -613	M$ -869	M$ -1.137
	$ 11.200	M$ -1.116	M$ -1.335	M$ -1.567	M$ -1.810	M$ -2.054	M$ -2.310	M$ -2.578
	$ 12.510	M$ -2.557	M$ -2.776	M$ -3.008	M$ -3.251	M$ -3.495	M$ -3.751	M$ -4.019
	$ 13.820	M$ -3.998	M$ -4.217	M$ -4.449	M$ -4.692	M$ -4.936	M$ -5.192	M$ -5.460
	$ 15.130	M$ -5.439	M$ -5.658	M$ -5.890	M$ -6.133	M$ -6.377	M$ -6.633	M$ -6.901

Based on these figures we can conclude that Italy definitely has the figures to render these initiatives other than environmentally sustainable, financially profitable. To further grasp the environmental impact of this solution, section 4 will analyze the likely future situation.

PHASE 4

In terms of actual city size and urban development forecast in Italy, table 60 summarizes the situation while fig 92 provides a graphic representation on the hypothesis made to quantify the magnitude of the infrastructural deterioration proportionally to the speed of city growth as a function of their size. The quadratic equation used in this simulation is set to hit a value of 20% of relative increase for the rise of a new city of 10 million inhabitants.

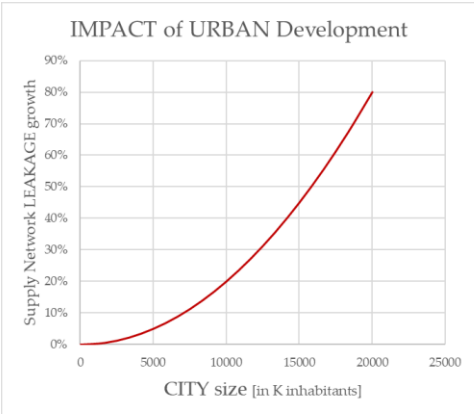
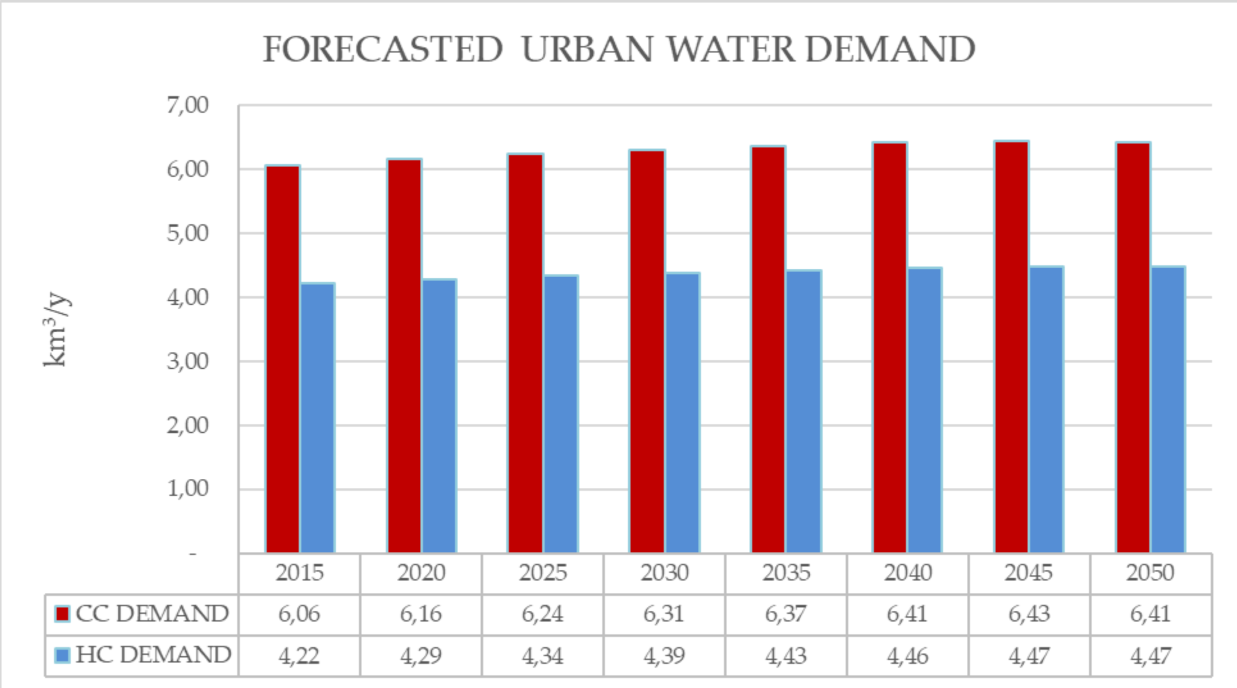


Fig. 92 Infrastructural deterioration as a function of city size

Table 60 Forecasted city size growth and resulting infrastructural deterioration

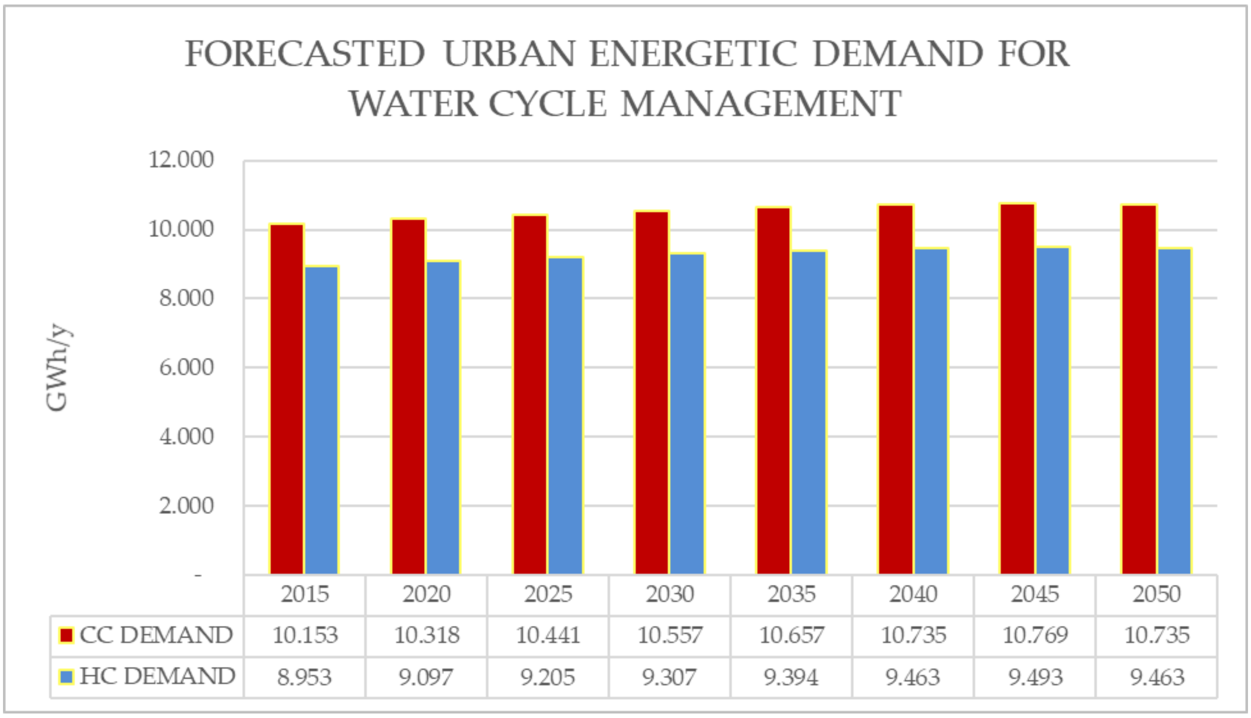
Data type	Size class	2015	2020	2025	2030	2035
Number of Agglomerations	10 million or more	0	0	0	0	0
Population	10 million or more	0	0	0	0	0
Number of Agglomerations	5 to 10 million	2	2	2	2	2
Population	5 to 10 million	11498	12203	12544	12719	12844
Number of Agglomerations	1 to 5 million	0	0	0	0	0
Population	1 to 5 million	0	0	0	0	0
Number of Agglomerations	500 000 to 1 million	4	4	5	5	5
Population	500 000 to 1 million	2794	2858	3397	3436	3469
Number of Agglomerations	300 000 to 500 000	8	8	7	7	7
Population	300 000 to 500 000	2934	3044	2575	2604	2629
Percentage of Urban Population	Fewer than 300 000	53%	52%	51%	51%	51%
Resulting Supply leakage VARIATION			0,5%	0,2%	0,1%	0,1%

Such computations are needed to forecast the water and consequent energetic demand for domestic consumption up to 2050 (fig 93 and fig 94).



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	6,06	6,16	6,24	6,31	6,37	6,41	6,43	6,41
HC DEMAND	4,22	4,29	4,34	4,39	4,43	4,46	4,47	4,47

Fig 93 Forecasted urban water demand



	2015	2020	2025	2030	2035	2040	2045	2050
CC DEMAND	10.153	10.318	10.441	10.557	10.657	10.735	10.769	10.735
HC DEMAND	8.953	9.097	9.205	9.307	9.394	9.463	9.493	9.463

Fig 94 Forecasted urban energetic demand for water cycle management

Figure 95 verifies how total water withdrawal from human activities, industrial, agricultural, and domestic, checks against the available renewable resource Italy. The yellow line represents a cap set at 70% of the total value due to seasonality and the potential inaccessibility of the resource.

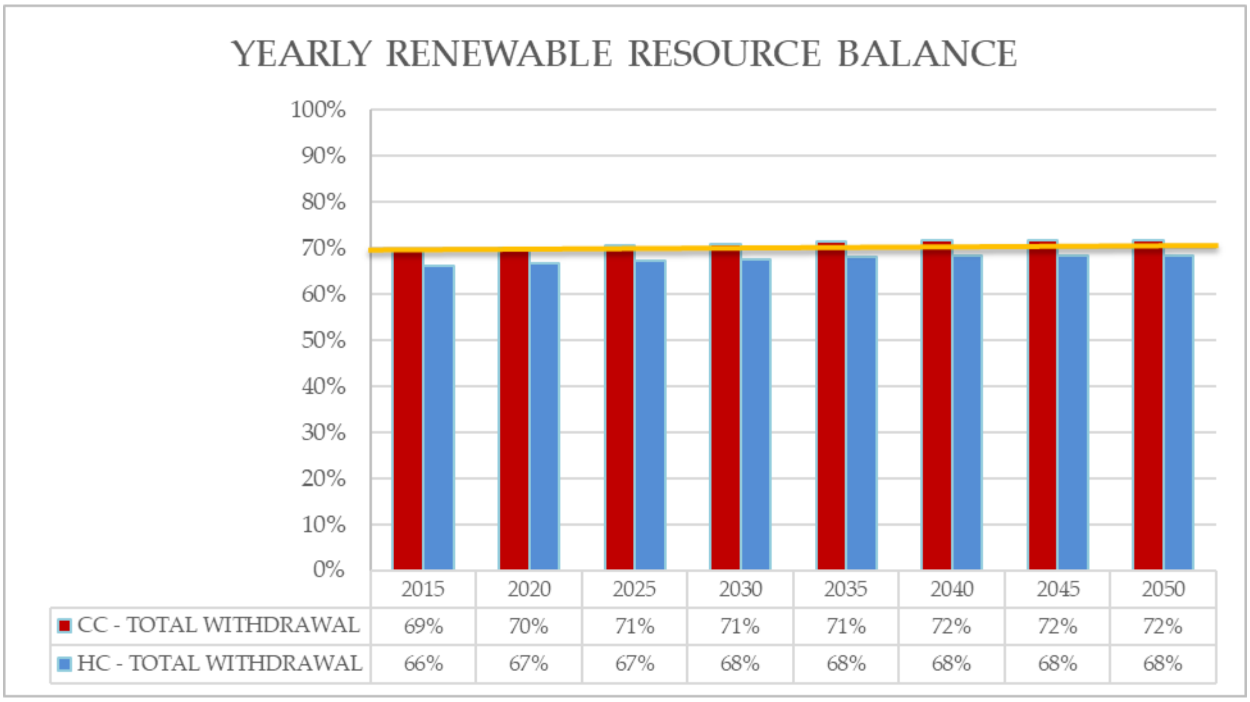


Fig 95 Yearly renewable resource balance

The 2015-2050 total estimated resources lost are highlighted in figure 96

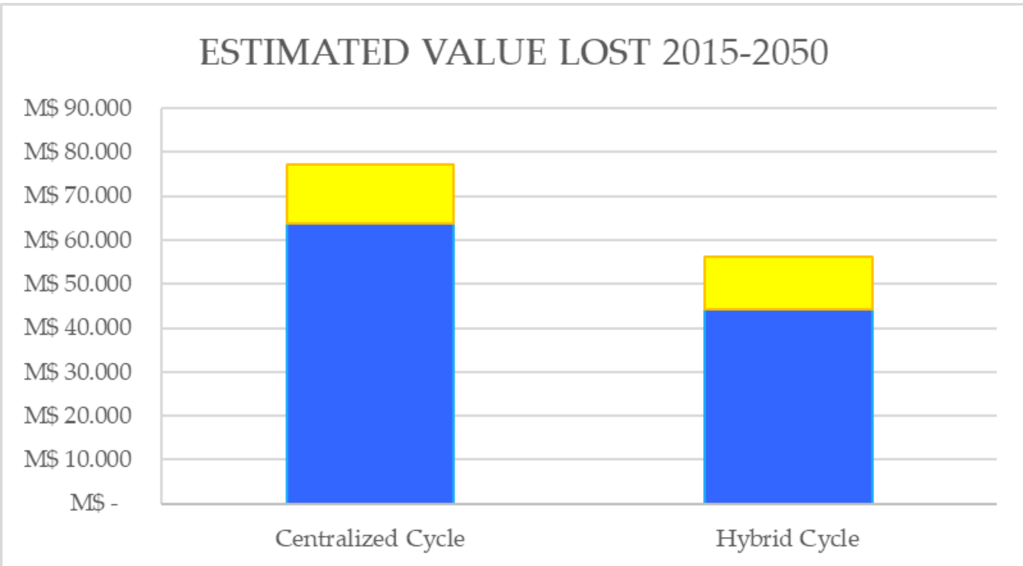


Fig 96 Estimated value lost 2015-2050

CONCLUSION

This research aimed to identify whether a change in paradigm is required for urban water management. Based on the quantitative and qualitative analysis gathered in the first three chapters and funneled through the model in the last section, it can be concluded that, with the exception of the countries which still have to develop economically, implementing a hybrid cycle would have a significant impact from a resource saving perspective and constitute also a valuable financial investment. These results have to be always considered in light of the assumption; while the unavailability of specific local data limits the precision of the results, this approach aimed at developing a tool for future monitoring and planning.

In having progressively analyzed the single steps on the path later followed by the model, the reader certainly grasped the magnitude of the variables and the intrinsic complexity of their correlations. Simplifying such relations and managing to find a final figure is always a tough game in which one must partially give-in in order to get something back. Using nature's laws as a blueprint to face modern complex problems is the process followed in structuring this paper.

The model has been developed with the potential to go as deep as the user desires limited only by data availability. The "result" tables illustrated when discussing model's output are presented as top-down for clearness but have a bottom-up logic allowing the user to start from the most basic building block. For example, the reasoning could be developed starting from real data of each household, agglomerating households to form a neighborhood and progressively build cities and whole countries. The eagle eye provided by such an approach is perfectly fitting with the needs of analysts, researchers and policy-makers whose role is to take decisions with foresight in order to lead society. Technological advancements grant the possibility of almost illimited data collection, sensors are easily accessible and IoT is providing the world with new surprising insights.

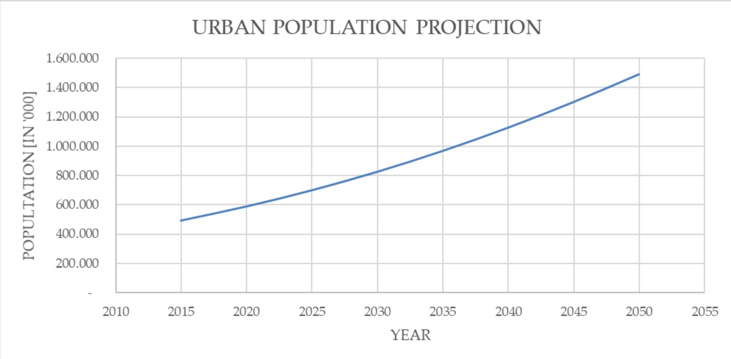
There is still a great amount of work to do in data collection and in studying the correlations that have been here assumed. Infrastructural deterioration is one of the most significant fragilities of today's water system. Hard to monitor, to replace and to expand it is an urgent constraint to address in fast growing cities. Perhaps the most significant challenge of all, that is only caressed by this paper, is the final reasoning of the model; the projection of future withdrawal. As stated in the introductory stages and represented in different ways during the model explanation, urban water consumption is a relatively small percentage with respect to the annual withdrawal for agricultural, farming and industrial uses. Dietary habits and education in this sense will truly determine management of the planet's resources and hence its future.

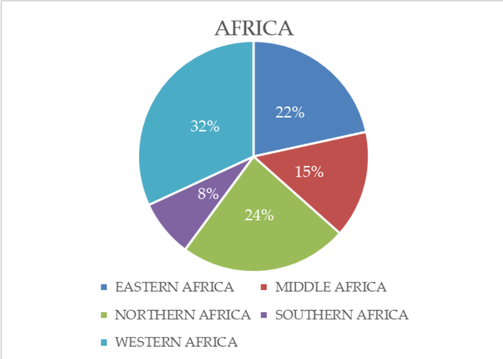
This work tried to investigate a complex problem looking for the solution in mimicking nature by reducing the system's fragility in the never-ending quest of regaining that natural antifragility which we daily surrender in the name of financial gains. In this era of self-presumed superhumans we arrogantly take pride on the illusion of out-living nature itself. The bigger we grow and the humbler and more receptive of nature we need to be in order to survive.

APPENDIX

Exhibit 1

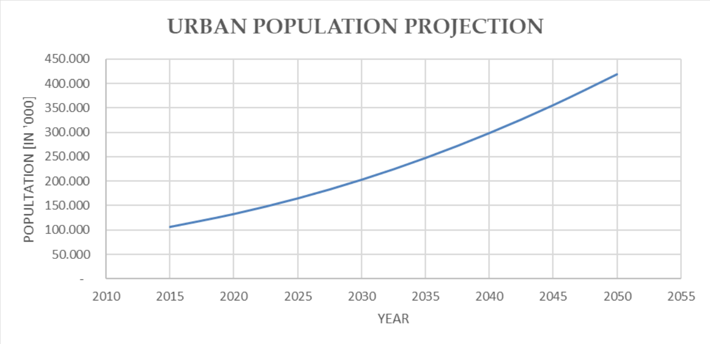
AFRICA

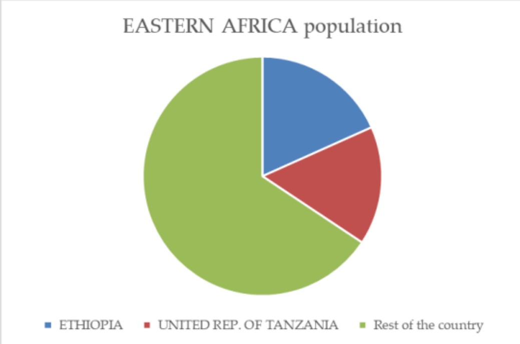




AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,04
min WATER price Growth rate for NPV>=0		19%
min ENERGY PRICE for NPV>=0	$	5,65
min ENERGY price Growth rate for NPV>=0		49%
min 9m3/day treatment unit price	$	-19.176
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		20,38
avg actual domestic demand 2015-2050 HC [km3/year]		13,77
DELTA		-32%
avg actual energy demand in CC [GWh/year]		17.833
avg actual energy demand in HC [GWh/year]		15.846
DELTA		-11%
PV of water lost in CC	M$	-518.342
PV of water lost in HC	M$	-350.310
PV of water savings with HC in 35years	M$	168.032
PV of energy consumed in CC	M$	129.788
PV of energy consumed in HC	M$	113.166
PV of energy expenditure if adoptiong HC for next 35years	M$	-16.622
WATER STRESS LEVEL(% of renewable resource used)		89%

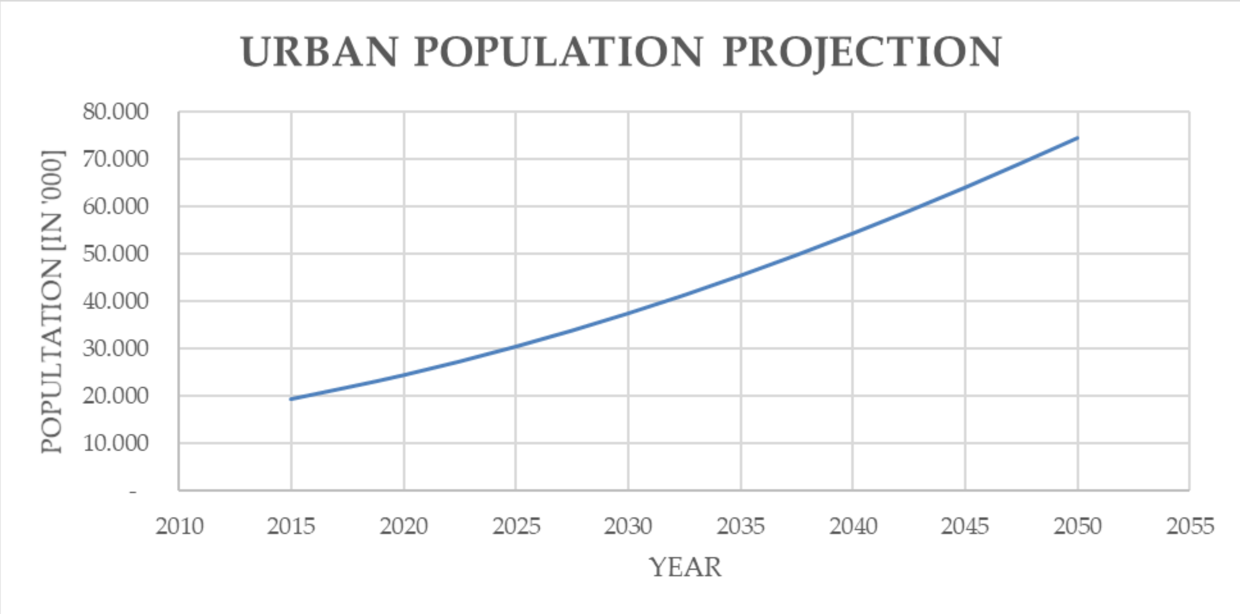
EASTERN AFRICA





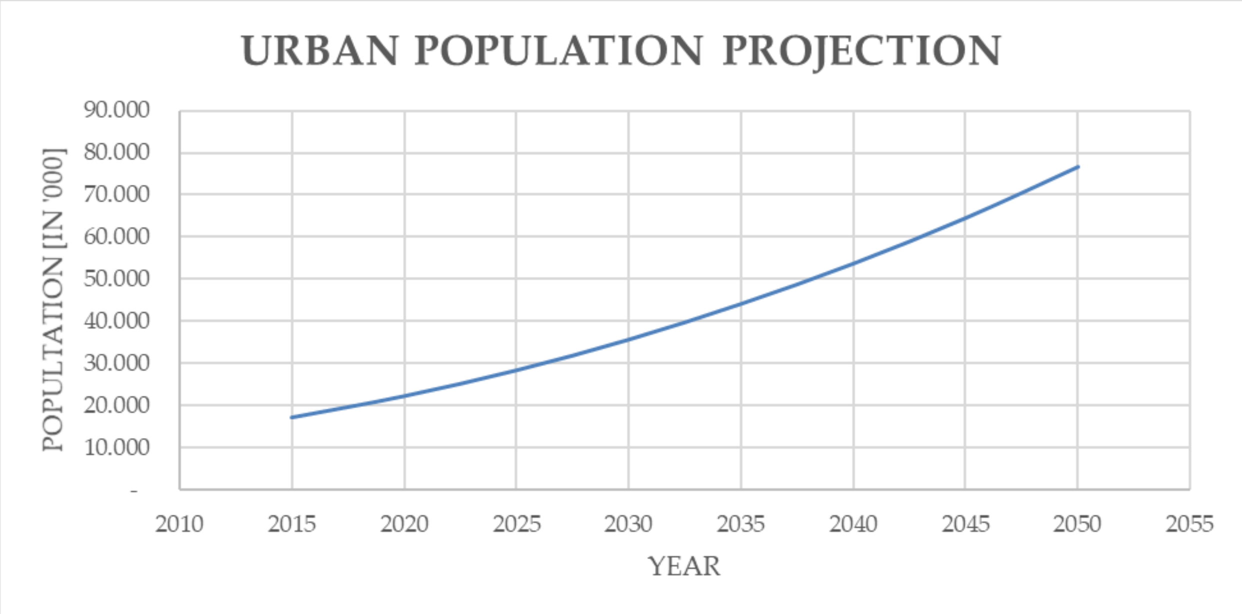
EASTERN AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,04
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	3,77
min ENERGY price Growth rate for NPV>=0		42%
min 9m3/day treatment unit price	$	-23.754
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		12,40
avg actual domestic demand 2015-2050 HC [km3/year]		8,27
DELTA		-33%
avg actual energy demand in CC [GWh/year]		12.338
avg actual energy demand in HC [GWh/year]		10.986
DELTA		-11%
PV of water lost in CC	M$	-60.813
PV of water lost in HC	M$	-40.409
PV of water savings with HC in 35years	M$	20.404
PV of energy consumed in CC	M$	26.785
PV of energy consumed in HC	M$	23.420
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.365
WATER STRESS LEVEL(% of renewable resource used)		47%

EASTERN AFRICA – ETHIOPIA



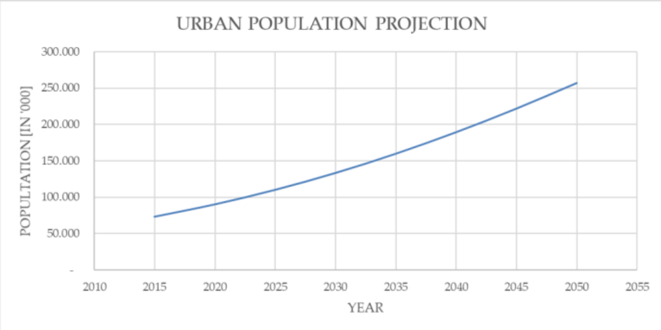
ETHIOPIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,18
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	5,13
min ENERGY price Growth rate for NPV>=0		47%
min 9m3/day treatment unit price	$	-24.189
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,52
avg actual domestic demand 2015-2050 HC [km^3/year]		1,03
DELTA		-33%
avg actual energy demand in CC [GWh/year]		1.617
avg actual energy demand in HC [GWh/year]		1.522
DELTA		-6%
PV of water lost in CC	M$	-6.068
PV of water lost in HC	M$	-4.097
PV of water savings with HC in 35years	M$	1.971
PV of energy consumed in CC	M$	2.144
PV of energy consumed in HC	M$	2.015
PV of energy expenditure if adoptiong HC for next 35years	M$	-128
WATER STRESS LEVEL(% of renewable water resource used)		38%

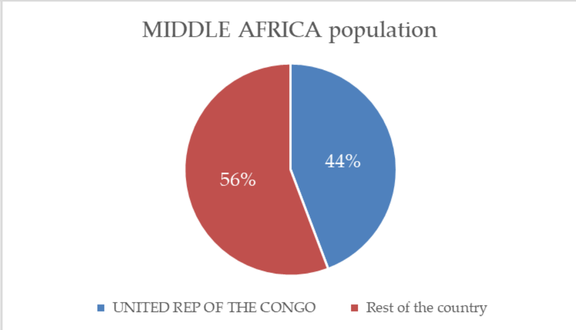
EASTERN AFRICA – UNITED REPUBLIC OF TANZANIA



UNITED REPUBLIC OF TANZANIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,89
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	2,21
min ENERGY price Growth rate for NPV>=0		36%
min 9m3/day treatment unit price	$	-23.258
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		2,74
avg actual domestic demand 2015-2050 HC [km^3/year]		1,82
DELTA		-34%
avg actual energy demand in CC [GWh/year]		2.620
avg actual energy demand in HC [GWh/year]		2.251
DELTA		-14%
PV of water lost in CC	M$	-14.818
PV of water lost in HC	M$	-9.781
PV of water savings with HC in 35years	M$	5.037
PV of energy consumed in CC	M$	7.056
PV of energy consumed in HC	M$	6.028
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.027
WATER STRESS LEVEL(% of renewable water resource used)		57%

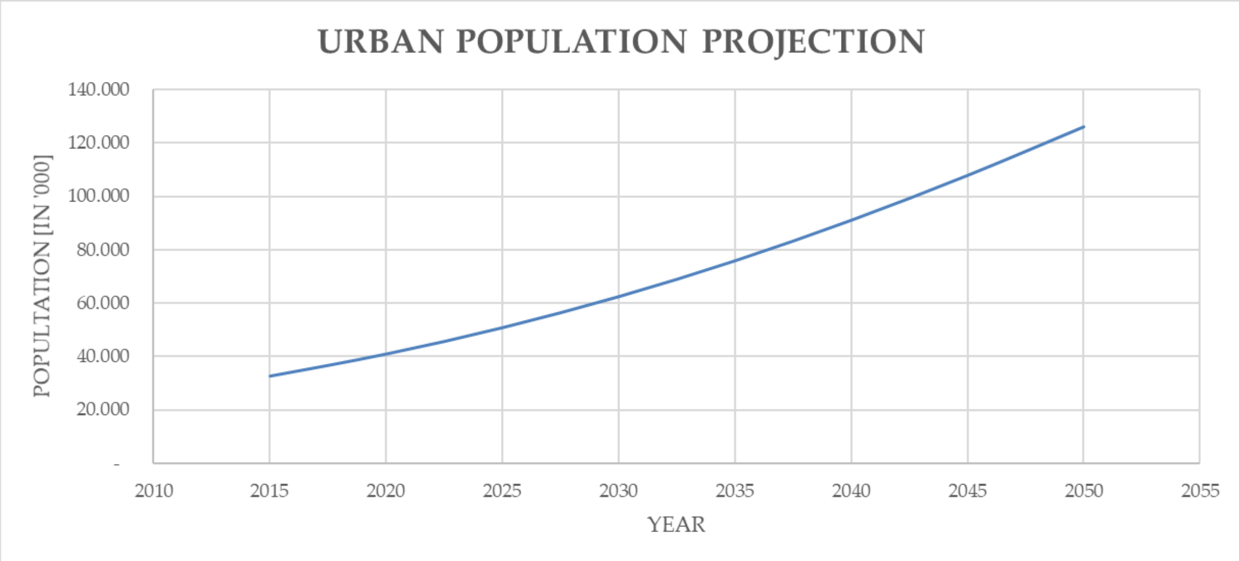
MIDDLE AFRICA





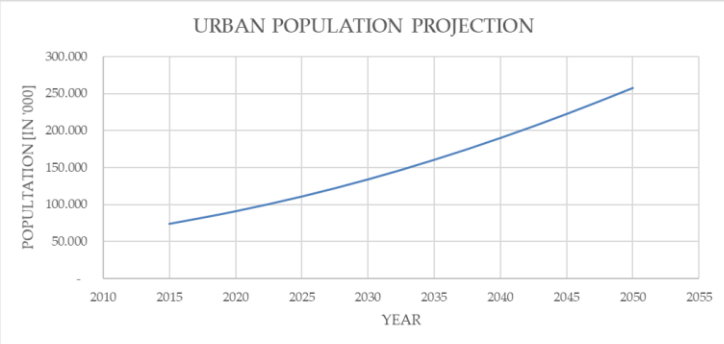
MIDDLE AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	0,94
min WATER price Growth rate for NPV>=0		14%
min ENERGY PRICE for NPV>=0	$	2,35
min ENERGY price Growth rate for NPV>=0		31%
min 9m3/day treatment unit price	$	-16.512
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		4,29
avg actual domestic demand 2015-2050 HC [km3/year]		2,87
DELTA		-33%
avg actual energy demand in CC [GWh/year]		4.057
avg actual energy demand in HC [GWh/year]		3.442
DELTA		-15%
PV of water lost in CC	M$	-84.879
PV of water lost in HC	M$	-56.742
PV of water savings with HC in 35years	M$	28.137
PV of energy consumed in CC	M$	45.001
PV of energy consumed in HC	M$	37.769
PV of energy expenditure if adoptiong HC for next 35years	M$	-7.232
WATER STRESS LEVEL(% of renewable resource used)		2%

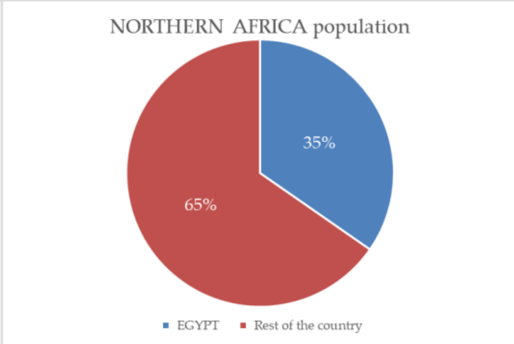
MIDDLE AFRICA – DEMOCRATIC REPUBLIC OF THE CONGO



UNITED REPUBLIC OF THE CONGO RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,94
min WATER price Growth rate for NPV>=0		14%
min ENERGY PRICE for NPV>=0	$	2,35
min ENERGY price Growth rate for NPV>=0		31%
min 9m3/day treatment unit price	$	-16.512
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,90
avg actual domestic demand 2015-2050 HC [km^3/year]		1,27
DELTA		-33%
avg actual energy demand in CC [GWh/year]		1.794
avg actual energy demand in HC [GWh/year]		1.522
DELTA		-15%
PV of water lost in CC	M$	-37.541
PV of water lost in HC	M$	-25.096
PV of water savings with HC in 35years	M$	12.445
PV of energy consumed in CC	M$	19.903
PV of energy consumed in HC	M$	16.705
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.199
WATER STRESS LEVEL(% of renewable water resource used)		2%

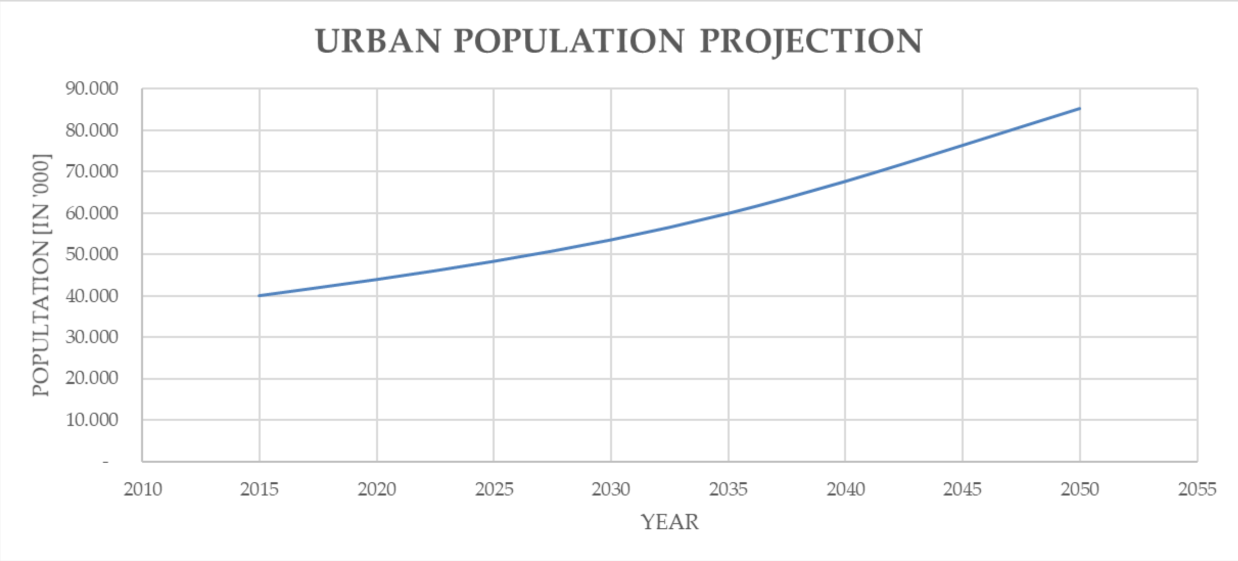
NORTHERN AFRICA





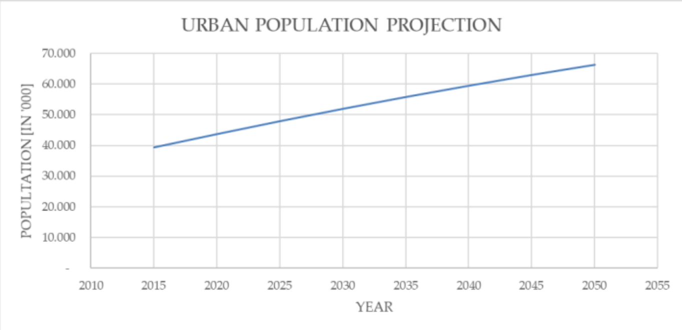
NORTHERN AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,13
min WATER price Growth rate for NPV>=0		39%
min ENERGY PRICE for NPV>=0	$	5,08
min ENERGY price Growth rate for NPV>=0		60%
min 9m3/day treatment unit price	$	-37.286
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		31,92
avg actual domestic demand 2015-2050 HC [km3/year]		21,78
DELTA		-32%
avg actual energy demand in CC [GWh/year]		31.243,62
avg actual energy demand in HC [GWh/year]		27.407,09
DELTA		-12%
PV of water lost in CC	M$	-21.085
PV of water lost in HC	M$	-14.426
PV of water savings with HC in 35years	M$	6.659
PV of energy consumed in CC	M$	15.306
PV of energy consumed in HC	M$	13.285
PV of energy expenditure if adoptiong HC for next 35years	M$	-2.020
WATER STRESS LEVEL(% of renewable resource used)		263%

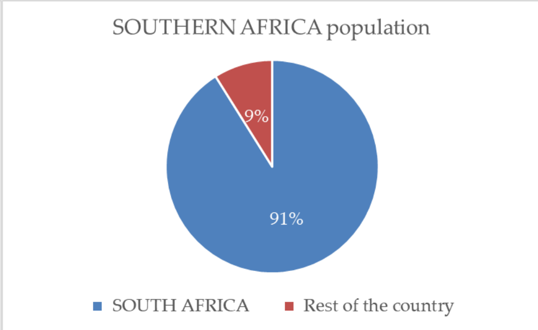
NORTHERN AFRICA – EGYPT



EGYPT RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,13
min WATER price Growth rate for NPV>=0		39%
min ENERGY PRICE for NPV>=0	$	5,08
min ENERGY price Growth rate for NPV>=0		60%
min 9m3/day treatment unit price	$	-37.286
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		11,07
avg actual domestic demand 2015-2050 HC [km^3/year]		7,55
DELTA		-32%
avg actual energy demand in CC [GWh/year]		10.834
avg actual energy demand in HC [GWh/year]		9.504
DELTA		-12%
PV of water lost in CC	M$	-7.312
PV of water lost in HC	M$	-5.003
PV of water savings with HC in 35years	M$	2.309
PV of energy consumed in CC	M$	5.308
PV of energy consumed in HC	M$	4.607
PV of energy expenditure if adoptiong HC for next 35years	M$	-701
WATER STRESS LEVEL(% of renewable water resource used)		263%

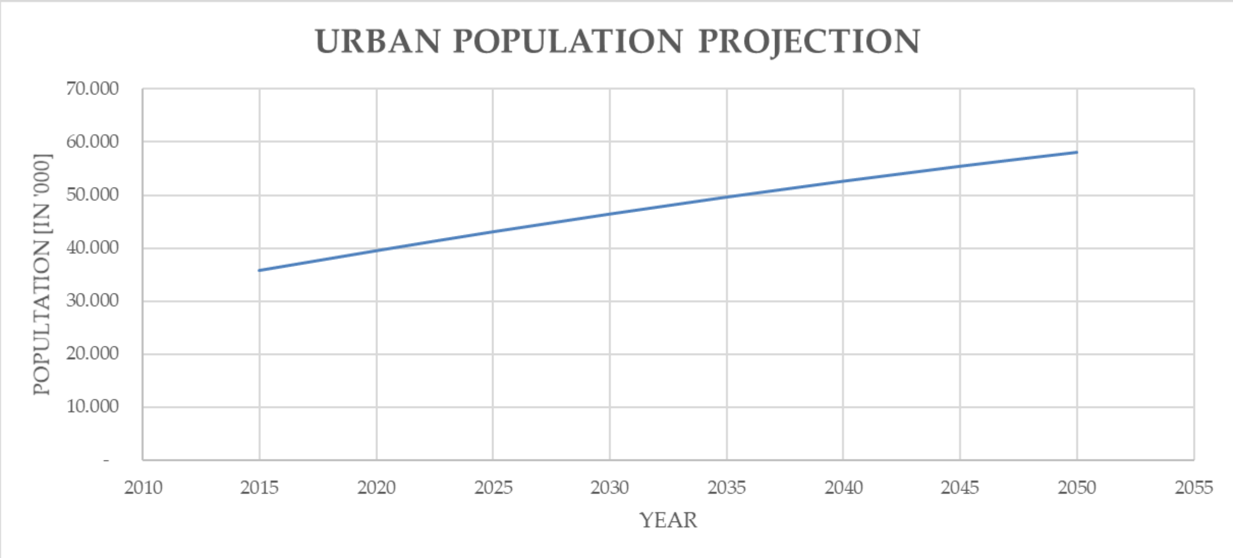
SOUTHERN AFRICA





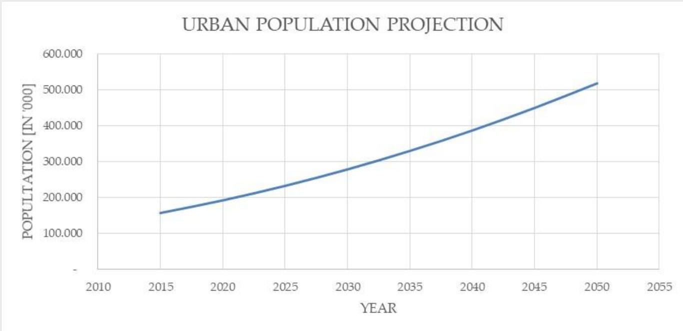
SOUTHERN AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,03
min WATER price Growth rate for NPV>=0		2%
min ENERGY PRICE for NPV>=0	$	1,96
min ENERGY price Growth rate for NPV>=0		33%
min 9m3/day treatment unit price	$	18.723
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		7,90
avg actual domestic demand 2015-2050 HC [km3/year]		5,46
DELTA		-35%
avg actual energy demand in CC [GWh/year]		6.439
avg actual energy demand in HC [GWh/year]		6.189
DELTA		-13%
PV of water lost in CC	M$	-95.764
PV of water lost in HC	M$	-66.260
PV of water savings with HC in 35years	M$	29.504
PV of energy consumed in CC	M$	10.277
PV of energy consumed in HC	M$	9.870
PV of energy expenditure if adoptiong HC for next 35years	M$	-408
WATER STRESS LEVEL(% of renewable resource used)		60%

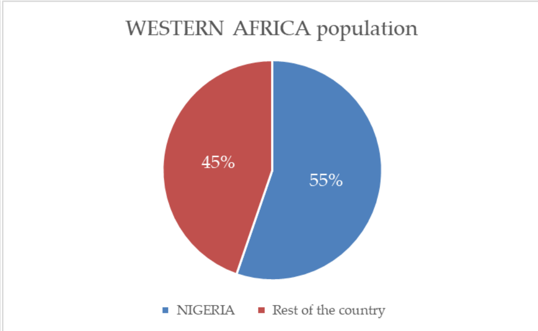
SOUTHERN AFRICA – SOUTH AFRICA



SOUTH AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,03
min WATER price Growth rate for NPV>=0		2%
min ENERGY PRICE for NPV>=0	$	1,96
min ENERGY price Growth rate for NPV>=0		33%
min 9m3/day treatment unit price	$	18.723
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		7,20
avg actual domestic demand 2015-2050 HC [km^3/year]		4,97
DELTA		-31%
avg actual energy demand in CC [GWh/year]		5.864
avg actual energy demand in HC [GWh/year]		5.637
DELTA		-4%
PV of water lost in CC	M$	-87.215
PV of water lost in HC	M$	-60.345
PV of water savings with HC in 35years	M$	26.870
PV of energy consumed in CC	M$	9.360
PV of energy consumed in HC	M$	8.989
PV of energy expenditure if adoptiong HC for next 35years	M$	-371
WATER STRESS LEVEL(% of renewable water resource used)		60%

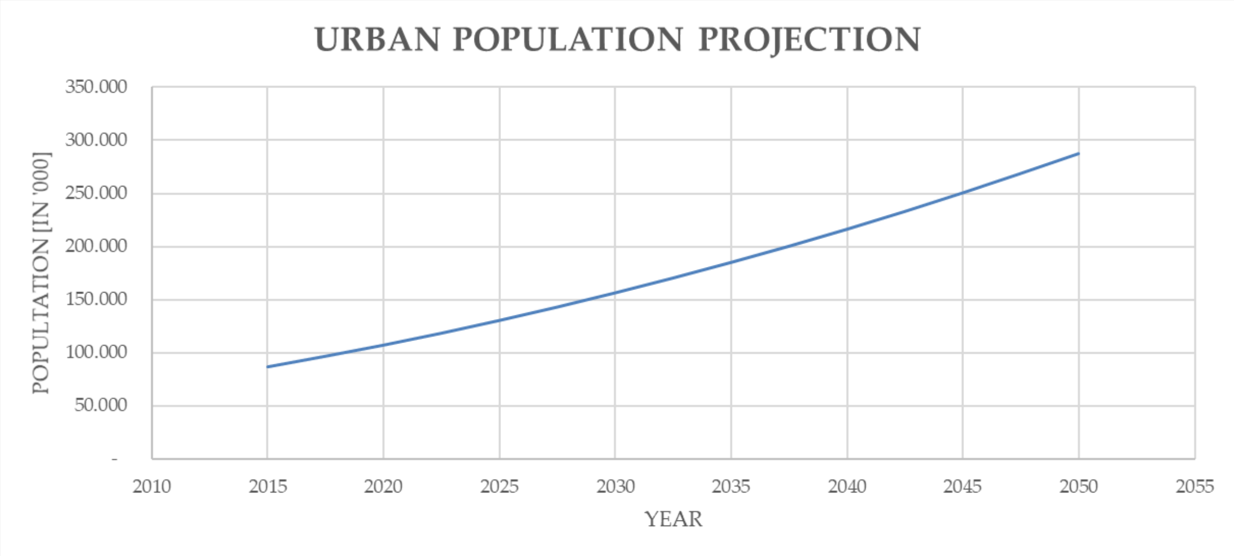
WESTERN AFRICA





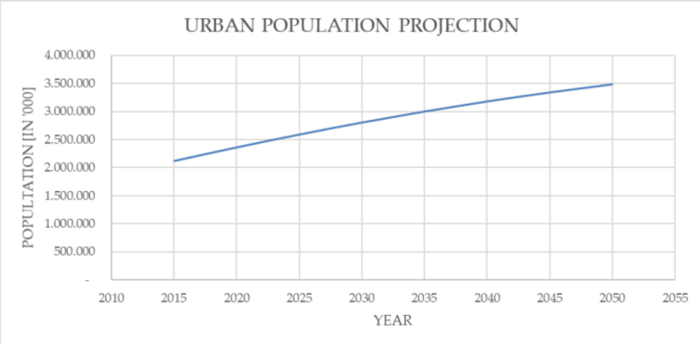
WESTERN AFRICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,03
min WATER price Growth rate for NPV>=0		11%
min ENERGY PRICE for NPV>=0	$	9,81
min ENERGY price Growth rate for NPV>=0		58%
min 9m3/day treatment unit price	$	-13.478
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		27,94
avg actual domestic demand 2015-2050 HC [km3/year]		18,78
DELTA		-59%
avg actual energy demand in CC [GWh/year]		20.986
avg actual energy demand in HC [GWh/year]		18.855
DELTA		-18%
PV of water lost in CC	M$	-255.801
PV of water lost in HC	M$	-172.473
PV of water savings with HC in 35years	M$	83.328
PV of energy consumed in CC	M$	32.418
PV of energy consumed in HC	M$	28.821
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.597
WATER STRESS LEVEL(% of renewable resource used)		37%

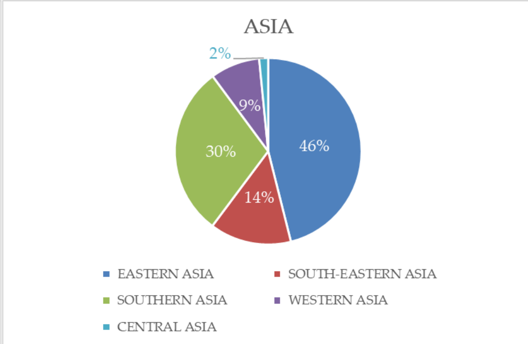
WESTERN AFRICA – NIGERIA



NIGERIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,03
min WATER price Growth rate for NPV>=0		11%
min ENERGY PRICE for NPV>=0	$	9,81
min ENERGY price Growth rate for NPV>=0		58%
min 9m3/day treatment unit price	$	-13.478
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		15,45
avg actual domestic demand 2015-2050 HC [km^3/year]		10,39
DELTA		-33%
avg actual energy demand in CC [GWh/year]		11.605
avg actual energy demand in HC [GWh/year]		10.426
DELTA		-10%
PV of water lost in CC	M$	-141.451
PV of water lost in HC	M$	-95.373
PV of water savings with HC in 35years	M$	46.078
PV of energy consumed in CC	M$	17.927
PV of energy consumed in HC	M$	15.937
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.989
WATER STRESS LEVEL(% of renewable water resource used)		37%

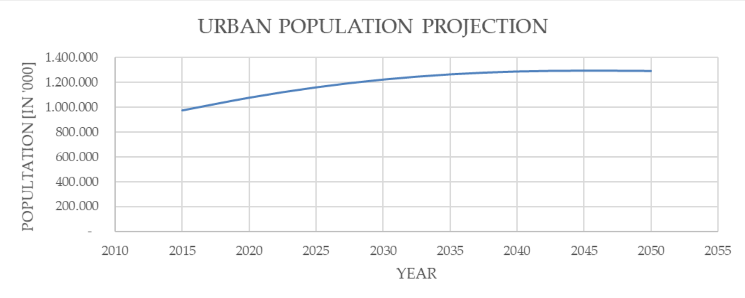
ASIA

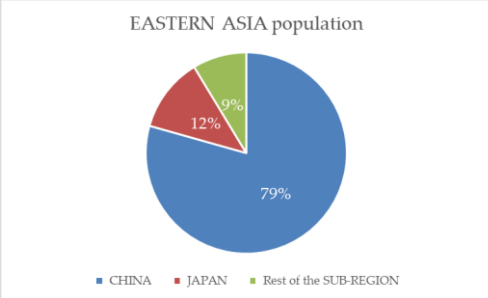




ASIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,05
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	4,28
min ENERGY price Growth rate for NPV>=0		46%
min 9m3/day treatment unit price	$	-21.761
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		87,01
avg actual domestic demand 2015-2050 HC [km3/year]		59,78
DELTA		-31%
avg actual energy demand in CC [GWh/year]		81.676
avg actual energy demand in HC [GWh/year]		72.459
DELTA		-11%
PV of water lost in CC	M$	-919.718
PV of water lost in HC	M$	-634.654
PV of water savings with HC in 35years	M$	285.064
PV of energy consumed in CC	M$	281.049
PV of energy consumed in HC	M$	248.720
PV of energy expenditure if adoptiong HC for next 35years	M$	-32.330
WATER STRESS LEVEL(% of renewable resource used)		70%

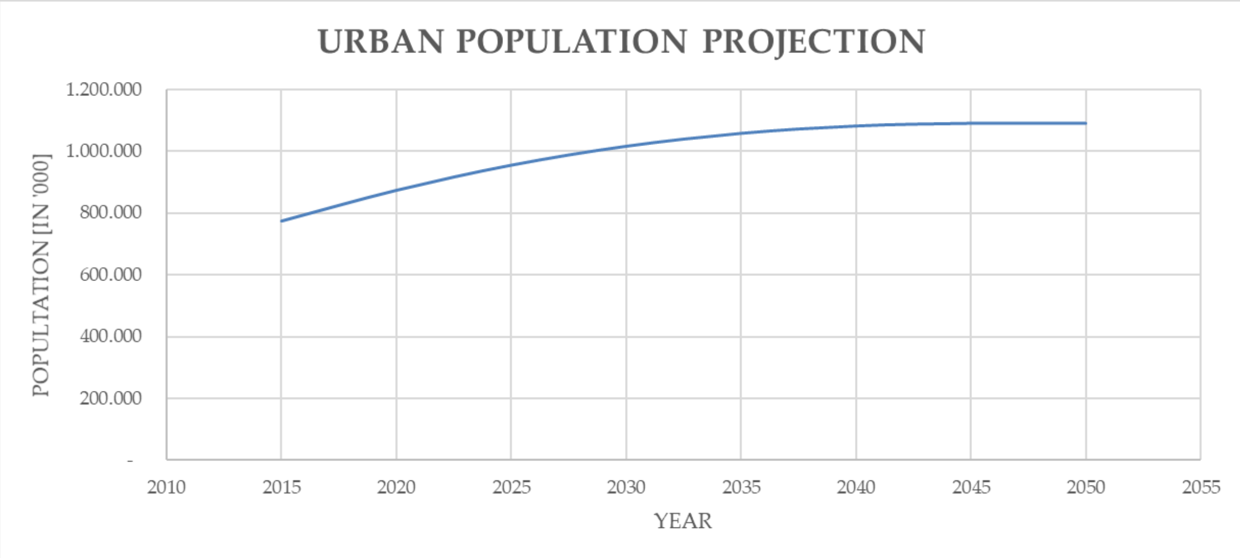
EASTERN ASIA





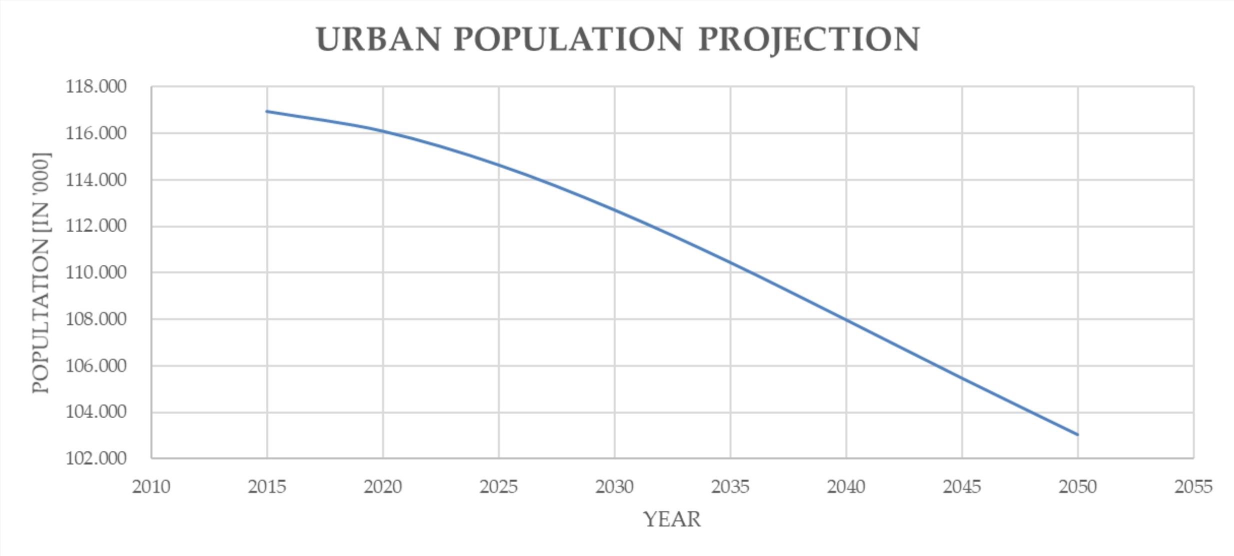
EASTERN ASIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,44
min WATER price Growth rate for NPV>=0		13%
min ENERGY PRICE for NPV>=0	$	-7,45
min ENERGY price Growth rate for NPV>=0		-279%
min 9m3/day treatment unit price	$	-5.889
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		238,66
avg actual domestic demand 2015-2050 HC [km3/year]		165,98
DELTA		-30%
avg actual energy demand in CC [GWh/year]		224.645
avg actual energy demand in HC [GWh/year]		227.648
DELTA		1%
PV of water lost in CC	M$	-584.173
PV of water lost in HC	M$	-406.339
PV of water savings with HC in 35years	M$	177.834
PV of energy consumed in CC	M$	156.201
PV of energy consumed in HC	M$	154.549
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.652
WATER STRESS LEVEL(% of renewable resource used)		59%

EASTERN ASIA – CHINA



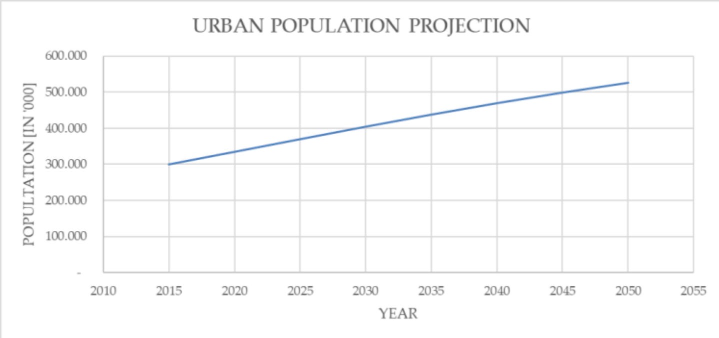
CHINA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,46
min WATER price Growth rate for NPV>=0		18%
min ENERGY PRICE for NPV>=0	$	-8,11
min ENERGY price Growth rate for NPV>=0		-285%
min 9m3/day treatment unit price	$	-24.923
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		117,03
avg actual domestic demand 2015-2050 HC [km^3/year]		81,36
DELTA		-30%
avg actual energy demand in CC [GWh/year]		107.678
avg actual energy demand in HC [GWh/year]		110.500
DELTA		3%
PV of water lost in CC	M$	-231.653
PV of water lost in HC	M$	-161.046
PV of water savings with HC in 35years	M$	70.607
PV of energy consumed in CC	M$	50.043
PV of energy consumed in HC	M$	51.248
PV of energy expenditure if adoptiong HC for next 35years	M$	1.205
WATER STRESS LEVEL(% of renewable water resource used)		38%

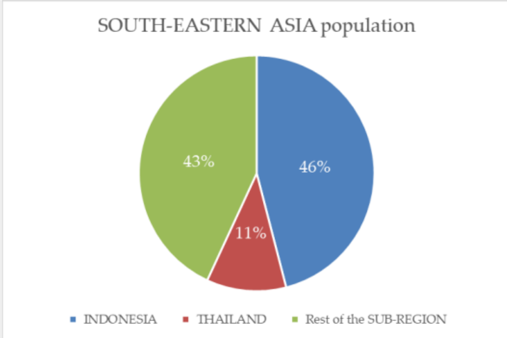
EASTERN ASIA – JAPAN



JAPAN RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,35
min WATER price Growth rate for NPV>=0		-9%
min ENERGY PRICE for NPV>=0	$	-4,70
min ENERGY price Growth rate for NPV>=0		-255%
min 9m3/day treatment unit price	$	74.112
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		18,78
avg actual domestic demand 2015-2050 HC [km^3/year]		13,09
DELTA		-30%
avg actual energy demand in CC [GWh/year]		20.156
avg actual energy demand in HC [GWh/year]		19.043
DELTA		-6%
PV of water lost in CC	M$	-100.771
PV of water lost in HC	M$	-70.181
PV of water savings with HC in 35years	M$	30.590
PV of energy consumed in CC	M$	38.843
PV of energy consumed in HC	M$	36.698
PV of energy expenditure if adoptiong HC for next 35years	M$	-2.145
WATER STRESS LEVEL(% of renewable water resource used)		29%

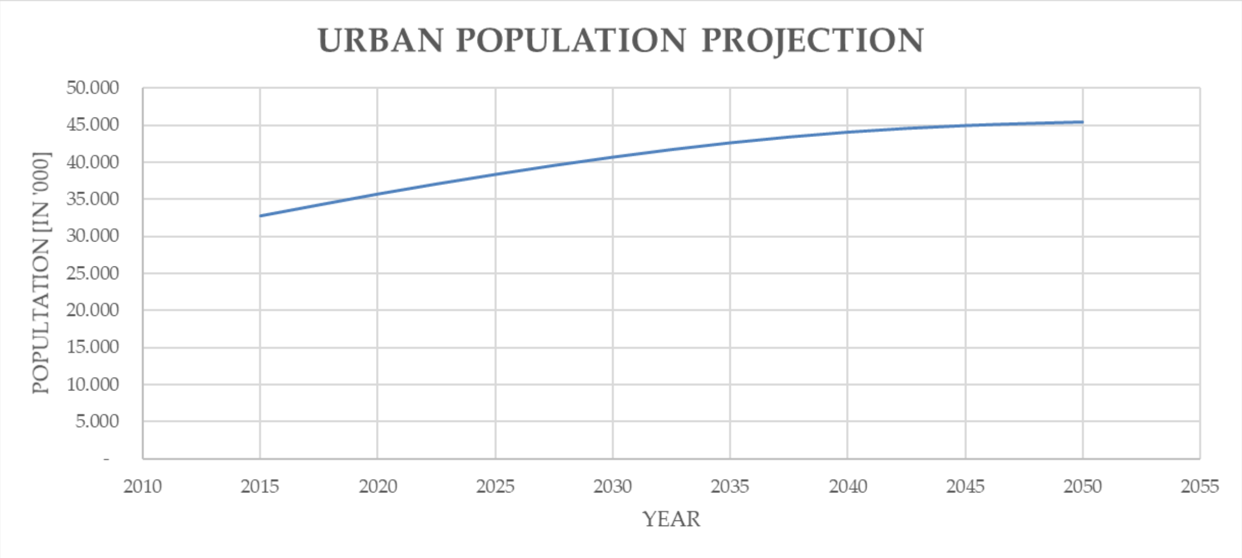
SOUTH-EASTERN ASIA





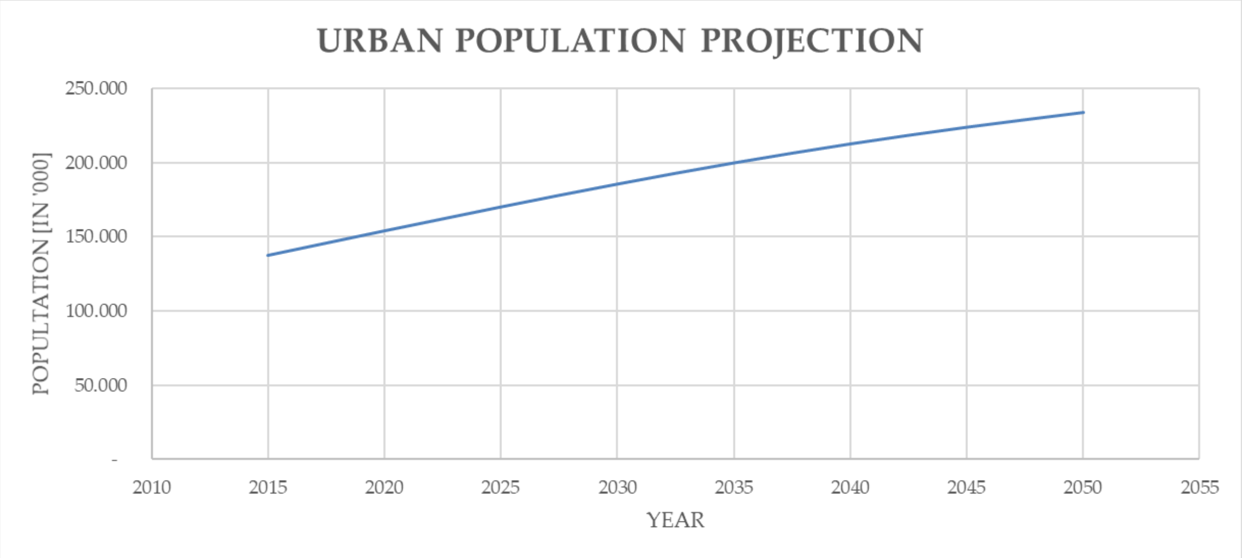
SOUTH-EASTERN ASIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,06
min WATER price Growth rate for NPV>=0		10%
min ENERGY PRICE for NPV>=0	$	3,10
min ENERGY price Growth rate for NPV>=0		37%
min 9m3/day treatment unit price	$	-9.007
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		61,29
avg actual domestic demand 2015-2050 HC [km3/year]		42,30
DELTA		-31%
avg actual energy demand in CC [GWh/year]		63.065
avg actual energy demand in HC [GWh/year]		57.856
DELTA		-8%
PV of water lost in CC	M$	-367.876
PV of water lost in HC	M$	-254.358
PV of water savings with HC in 35years	M$	113.518
PV of energy consumed in CC	M$	78.263
PV of energy consumed in HC	M$	71.593
PV of energy expenditure if adoptiong HC for next 35years	M$	-6.670
WATER STRESS LEVEL(% of renewable resource used)		32%

SOUTH-EASTERN ASIA – THAILAND



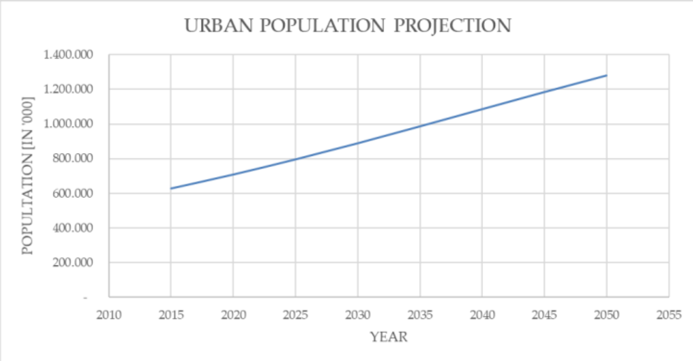
THAILAND RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,30
min WATER price Growth rate for NPV>=0		16%
min ENERGY PRICE for NPV>=0	$	7,93
min ENERGY price Growth rate for NPV>=0		49%
min 9m3/day treatment unit price	$	-21.627
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		4,47
avg actual domestic demand 2015-2050 HC [km^3/year]		3,10
DELTA		-31%
avg actual energy demand in CC [GWh/year]		4.875
avg actual energy demand in HC [GWh/year]		4.689
DELTA		-4%
PV of water lost in CC	M$	-10.905
PV of water lost in HC	M$	-7.571
PV of water savings with HC in 35years	M$	3.334
PV of energy consumed in CC	M$	4.077
PV of energy consumed in HC	M$	3.920
PV of energy expenditure if adoptiong HC for next 35years	M$	-157
WATER STRESS LEVEL(% of renewable water resource used)		21%

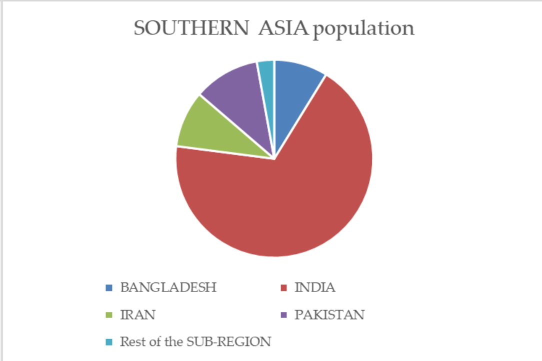
SOUTH-EASTERN ASIA – INDONESIA



INDONESIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,00
min WATER price Growth rate for NPV>=0		9%
min ENERGY PRICE for NPV>=0	$	1,95
min ENERGY price Growth rate for NPV>=0		35%
min 9m3/day treatment unit price	$	-6.004
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		30,41
avg actual domestic demand 2015-2050 HC [km^3/year]		20,97
DELTA		-31%
avg actual energy demand in CC [GWh/year]		31.012
avg actual energy demand in HC [GWh/year]		28.234
DELTA		-9%
PV of water lost in CC	M$	-198.435
PV of water lost in HC	M$	-137.171
PV of water savings with HC in 35years	M$	61.263
PV of energy consumed in CC	M$	40.459
PV of energy consumed in HC	M$	36.820
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.638
WATER STRESS LEVEL(% of renewable water resource used)		14%

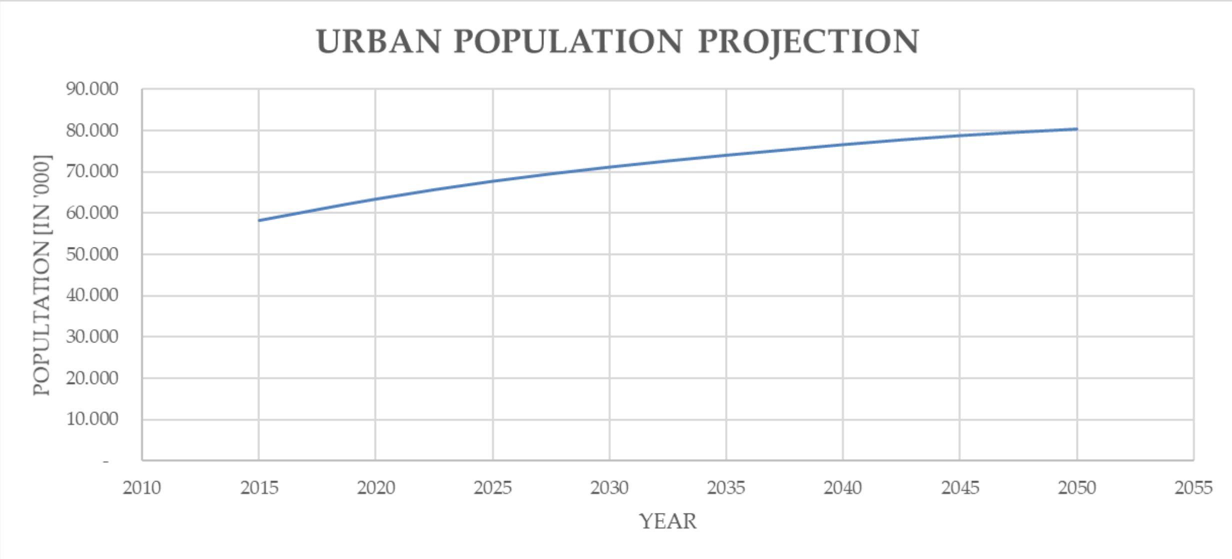
SOUTHERN ASIA





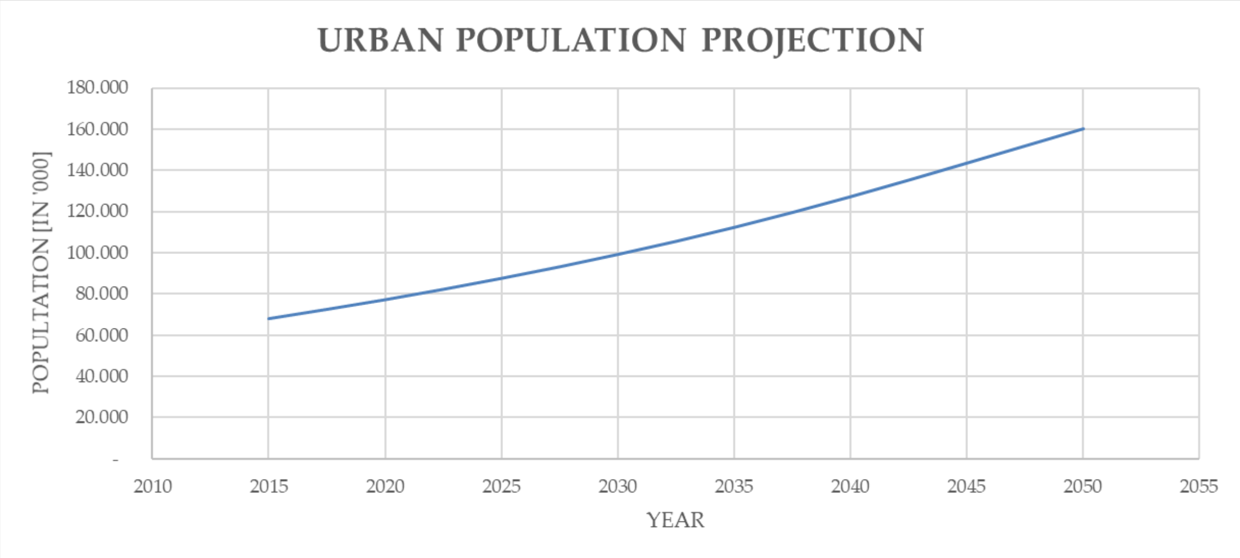
SOUTHERN ASIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,00
min WATER price Growth rate for NPV>=0		21%
min ENERGY PRICE for NPV>=0	$	3,75
min ENERGY price Growth rate for NPV>=0		46%
min 9m3/day treatment unit price	$	-27.373
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		138,87
avg actual domestic demand 2015-2050 HC [km3/year]		95,28
DELTA		-31%
avg actual energy demand in CC [GWh/year]		125.715
avg actual energy demand in HC [GWh/year]		109.876
DELTA		-13%
PV of water lost in CC	M$	-456.197
PV of water lost in HC	M$	-314.021
PV of water savings with HC in 35years	M$	142.176
PV of energy consumed in CC	M$	165.415
PV of energy consumed in HC	M$	142.939
PV of energy expenditure if adoptiong HC for next 35years	M$	-22.476
WATER STRESS LEVEL(% of renewable resource used)		108%

SOUTHERN ASIA – IRAN



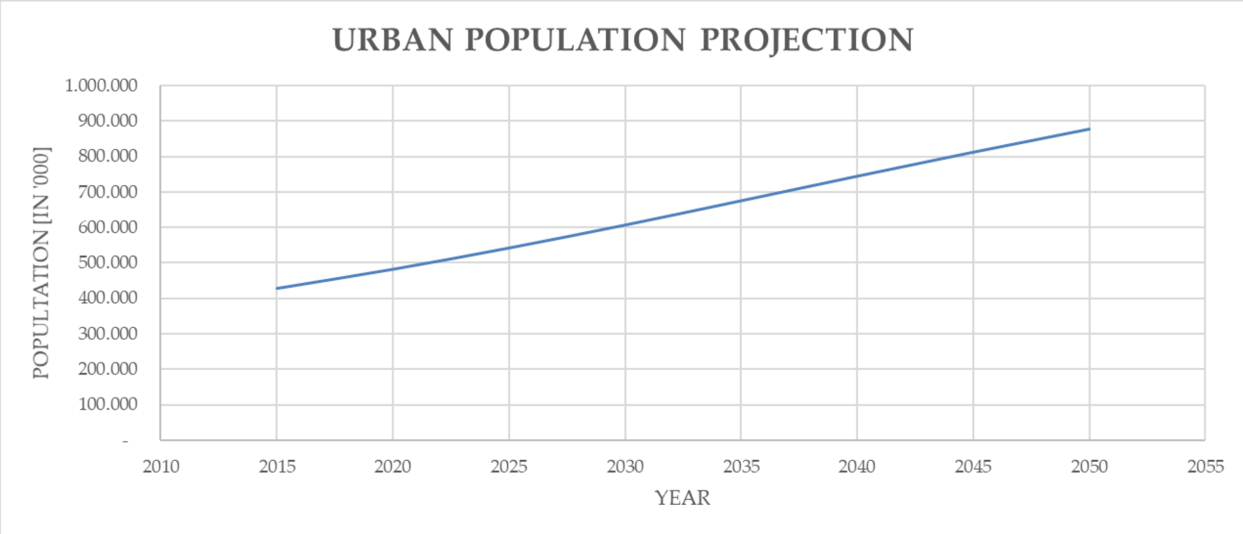
IRAN RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,14
min WATER price Growth rate for NPV>=0		31%
min ENERGY PRICE for NPV>=0	$	5,18
min ENERGY price Growth rate for NPV>=0		60%
min 9m3/day treatment unit price	$	-35.036
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		10,10
avg actual domestic demand 2015-2050 HC [km^3/year]		7,00
DELTA		-31%
avg actual energy demand in CC [GWh/year]		10.655
avg actual energy demand in HC [GWh/year]		9.983
DELTA		-6%
PV of water lost in CC	M$	-8.068
PV of water lost in HC	M$	-5.596
PV of water savings with HC in 35years	M$	2.471
PV of energy consumed in CC	M$	3.192
PV of energy consumed in HC	M$	2.990
PV of energy expenditure if adoptiong HC for next 35years	M$	-202
WATER STRESS LEVEL(% of renewable water resource used)		110%

SOUTHERN ASIA – PAKISTAN



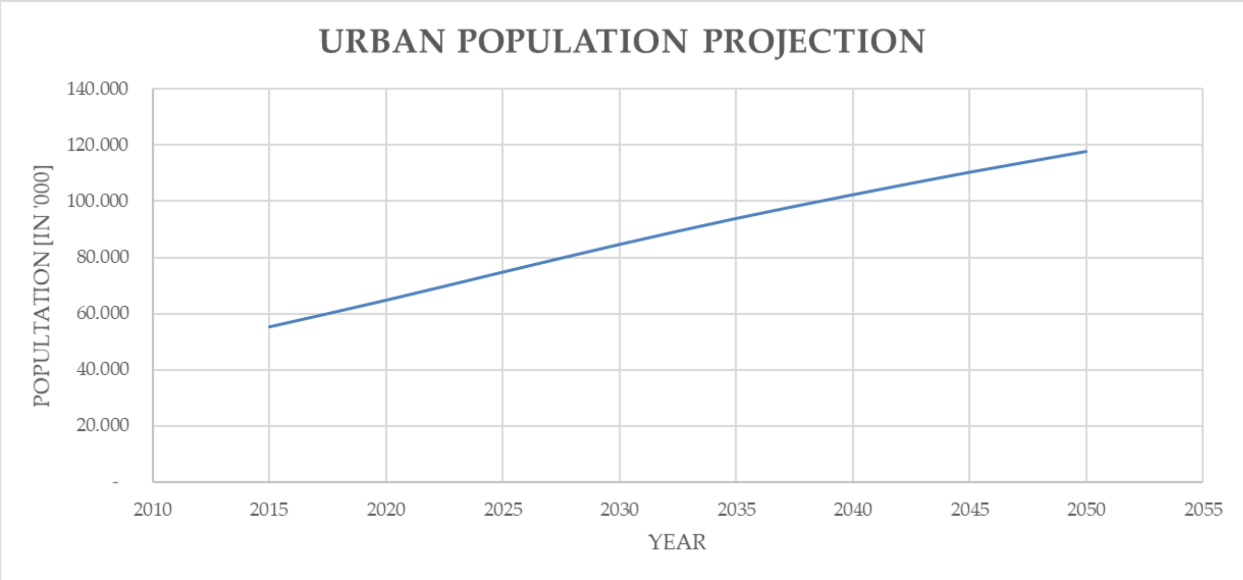
PAKISTAN RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,97
min WATER price Growth rate for NPV>=0		27%
min ENERGY PRICE for NPV>=0	$	3,04
min ENERGY price Growth rate for NPV>=0		46%
min 9m3/day treatment unit price	$	-32.106
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		18,22
avg actual domestic demand 2015-2050 HC [km^3/year]		12,40
DELTA		-32%
avg actual energy demand in CC [GWh/year]		17.552
avg actual energy demand in HC [GWh/year]		15.164
DELTA		-14%
PV of water lost in CC	M$	-32.552
PV of water lost in HC	M$	-22.257
PV of water savings with HC in 35years	M$	10.295
PV of energy consumed in CC	M$	18.715
PV of energy consumed in HC	M$	16.087
PV of energy expenditure if adoptiong HC for next 35years	M$	-2.628
WATER STRESS LEVEL(% of renewable water resource used)		273%

SOUTHERN ASIA – INDIA



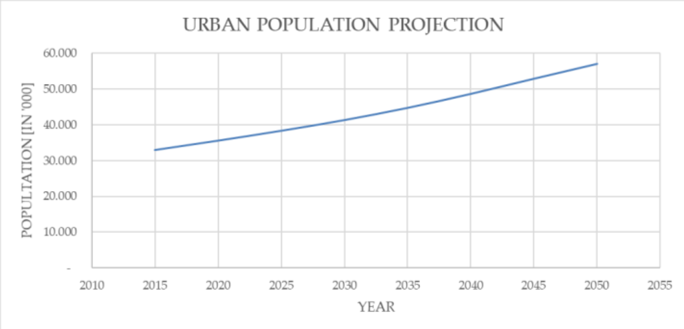
INDIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,97
min WATER price Growth rate for NPV>=0		19%
min ENERGY PRICE for NPV>=0	$	3,51
min ENERGY price Growth rate for NPV>=0		44%
min 9m3/day treatment unit price	$	-25.358
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		98,19
avg actual domestic demand 2015-2050 HC [km^3/year]		67,40
DELTA		-31%
avg actual energy demand in CC [GWh/year]		85.817
avg actual energy demand in HC [GWh/year]		74.576
DELTA		-13%
PV of water lost in CC	M$	-372.917
PV of water lost in HC	M$	-256.838
PV of water savings with HC in 35years	M$	116.080
PV of energy consumed in CC	M$	129.386
PV of energy consumed in HC	M$	111.757
PV of energy expenditure if adoptiong HC for next 35years	M$	-17.629
WATER STRESS LEVEL(% of renewable water resource used)		71%

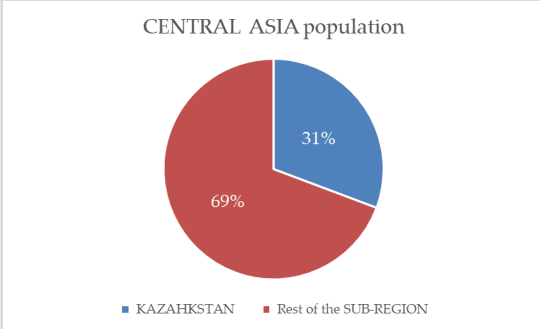
SOUTHERN ASIA – BANGLADESH



BANGLADESH RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,15
min WATER price Growth rate for NPV>=0		22%
min ENERGY PRICE for NPV>=0	$	4,98
min ENERGY price Growth rate for NPV>=0		52%
min 9m3/day treatment unit price	$	-29.105
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		8,39
avg actual domestic demand 2015-2050 HC [km^3/year]		5,76
DELTA		-31%
avg actual energy demand in CC [GWh/year]		8.105
avg actual energy demand in HC [GWh/year]		7.018
DELTA		-13%
PV of water lost in CC	M$	-29.649
PV of water lost in HC	M$	-20.374
PV of water savings with HC in 35years	M$	9.275
PV of energy consumed in CC	M$	9.404
PV of energy consumed in HC	M$	8.028
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.376
WATER STRESS LEVEL(% of renewable water resource used)		186%

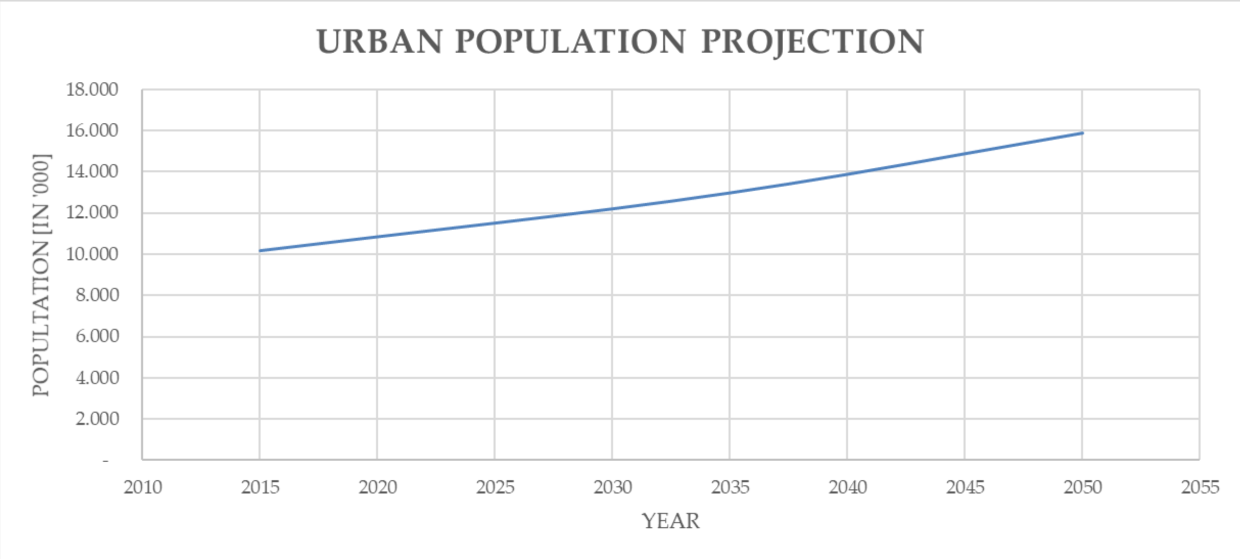
CENTRAL ASIA





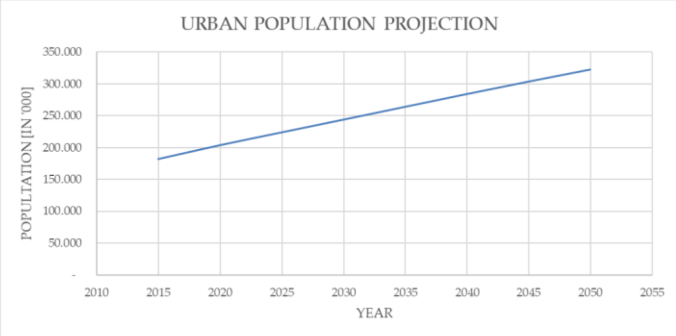
CENTRAL ASIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,31
min WATER price Growth rate for NPV>=0		23%
min ENERGY PRICE for NPV>=0	$	9,25
min ENERGY price Growth rate for NPV>=0		64%
min 9m3/day treatment unit price	$	-30.180
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		3,80
avg actual domestic demand 2015-2050 HC [km3/year]		2,61
DELTA		-31%
avg actual energy demand in CC [GWh/year]		4.164
avg actual energy demand in HC [GWh/year]		4.023
DELTA		-3%
PV of water lost in CC	M$	-4.592
PV of water lost in HC	M$	-3.171
PV of water savings with HC in 35years	M$	1.421
PV of energy consumed in CC	M$	1.061
PV of energy consumed in HC	M$	1.024
PV of energy expenditure if adoptiong HC for next 35years	M$	-36
WATER STRESS LEVEL(% of renewable resource used)		19%

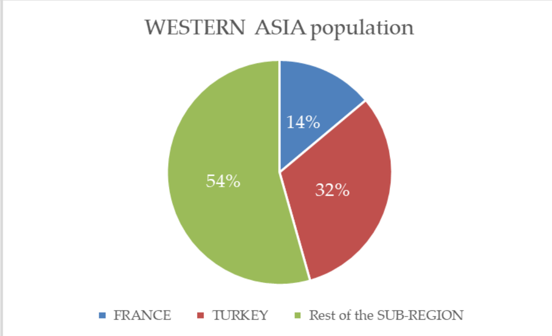
CENTRAL ASIA – KAZAHKSTAN



KAZAHKSTAN RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,31
min WATER price Growth rate for NPV>=0		23%
min ENERGY PRICE for NPV>=0	$	9,25
min ENERGY price Growth rate for NPV>=0		64%
min 9m3/day treatment unit price	$	-30.180
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,17
avg actual domestic demand 2015-2050 HC [km^3/year]		0,80
DELTA		-31%
avg actual energy demand in CC [GWh/year]		1.279
avg actual energy demand in HC [GWh/year]		1.235
DELTA		-3%
PV of water lost in CC	M$	-1.410
PV of water lost in HC	M$	-974
PV of water savings with HC in 35years	M$	436
PV of energy consumed in CC	M$	326
PV of energy consumed in HC	M$	315
PV of energy expenditure if adoptiong HC for next 35years	M$	-11
WATER STRESS LEVEL(% of renewable water resource used)		19%

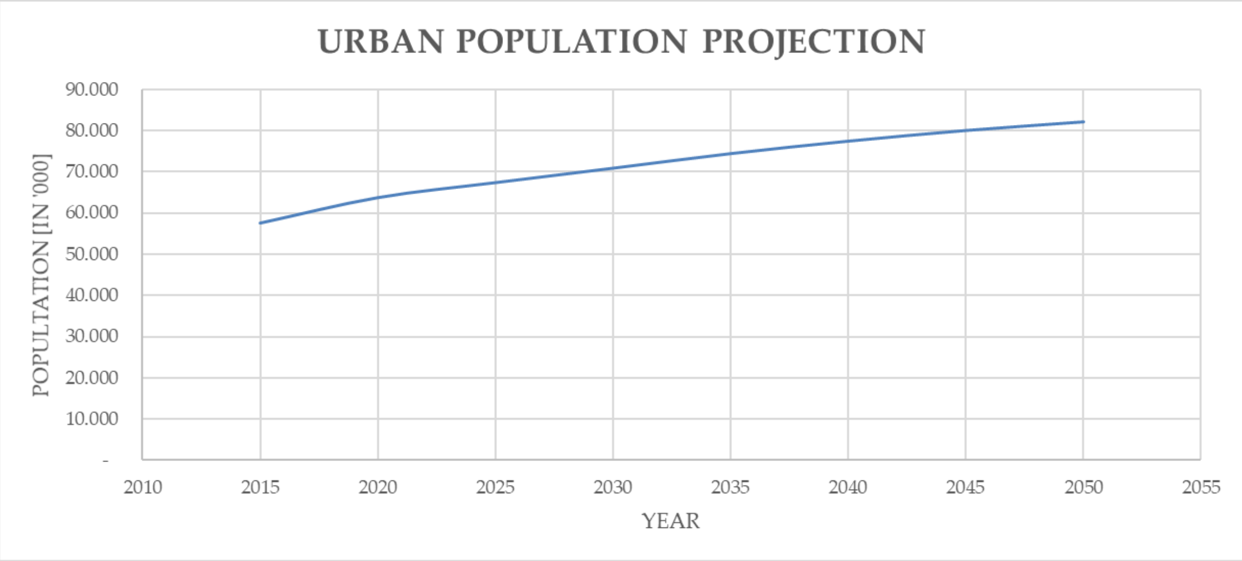
WESTERN ASIA





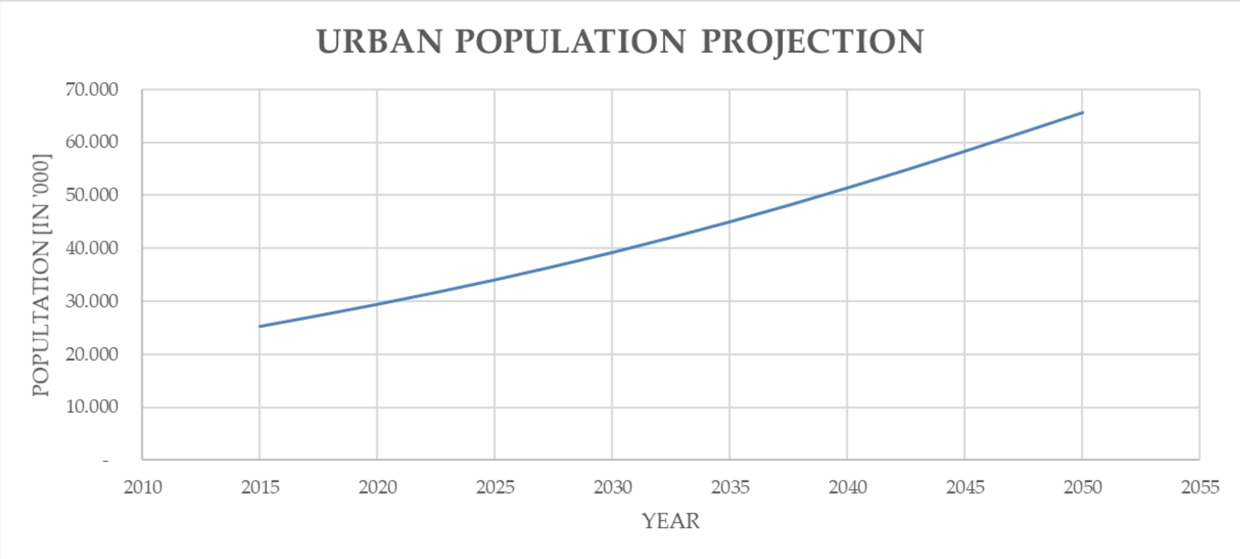
WESTERN ASIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,07
min WATER price Growth rate for NPV>=0		27%
min ENERGY PRICE for NPV>=0	$	3,82
min ENERGY price Growth rate for NPV>=0		47%
min 9m3/day treatment unit price	$	-25.812
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		50,18
avg actual domestic demand 2015-2050 HC [km3/year]		34,38
DELTA		-31%
avg actual energy demand in CC [GWh/year]		51.851
avg actual energy demand in HC [GWh/year]		47.741
DELTA		-8%
PV of water lost in CC	M$	-91.052
PV of water lost in HC	M$	-63.103
PV of water savings with HC in 35years	M$	27.949
PV of energy consumed in CC	M$	36.312
PV of energy consumed in HC	M$	33.163
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.148
WATER STRESS LEVEL(% of renewable resource used)		90%

WESTERN ASIA – TURKEY



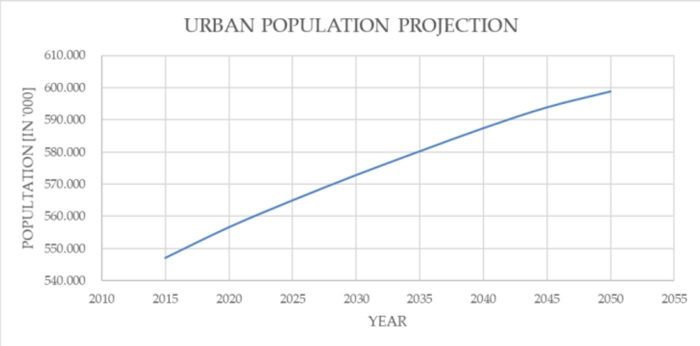
TURKEY RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,04
min WATER price Growth rate for NPV>=0		15%
min ENERGY PRICE for NPV>=0	$	3,08
min ENERGY price Growth rate for NPV>=0		41%
min 9m3/day treatment unit price	$	-20.003
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		10,08
avg actual domestic demand 2015-2050 HC [km^3/year]		6,98
DELTA		-31%
avg actual energy demand in CC [GWh/year]		10.257
avg actual energy demand in HC [GWh/year]		9.320
DELTA		-9%
PV of water lost in CC	M$	-40.161
PV of water lost in HC	M$	-27.847
PV of water savings with HC in 35years	M$	12.314
PV of energy consumed in CC	M$	12.243
PV of energy consumed in HC	M$	11.110
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.132
WATER STRESS LEVEL(% of renewable water resource used)		36%

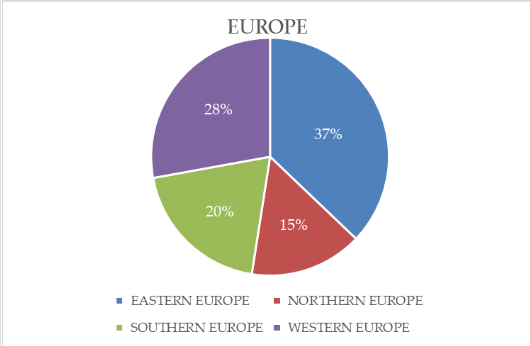
WESTERN ASIA – IRAQ



IRAQ RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,14
min WATER price Growth rate for NPV>=0		55%
min ENERGY PRICE for NPV>=0	$	5,52
min ENERGY price Growth rate for NPV>=0		61%
min 9m3/day treatment unit price	$	-39.067
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		12,81
avg actual domestic demand 2015-2050 HC [km^3/year]		8,70
DELTA		-32%
avg actual energy demand in CC [GWh/year]		13.399
avg actual energy demand in HC [GWh/year]		12.460
DELTA		-7%
PV of water lost in CC	M$	-1.379
PV of water lost in HC	M$	-942
PV of water savings with HC in 35years	M$	436
PV of energy consumed in CC	M$	4.323
PV of energy consumed in HC	M$	4.019
PV of energy expenditure if adoptiong HC for next 35years	M$	-304
WATER STRESS LEVEL(% of renewable water resource used)		214%

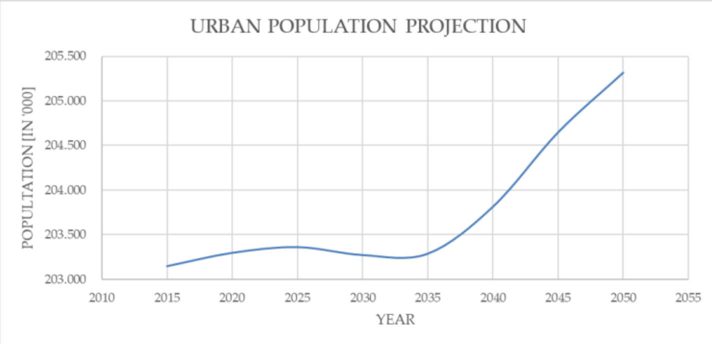
EUROPE

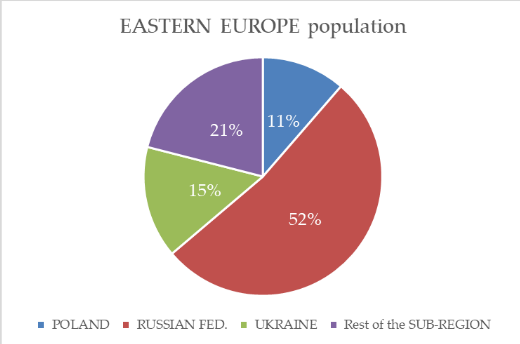




EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	1,16
min WATER price Growth rate for NPV>=0		-6%
min ENERGY PRICE for NPV>=0	$	-0,97
min ENERGY price Growth rate for NPV>=0		-155%
min 9m3/day treatment unit price	$	80.882
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		21,77
avg actual domestic demand 2015-2050 HC [km3/year]		15,12
DELTA		-31%
avg actual energy demand in CC [GWh/year]		27.639
avg actual energy demand in HC [GWh/year]		25.333
DELTA		-8%
PV of water lost in CC	M$	-1.472.710
PV of water lost in HC	M$	-1.022.797
PV of water savings with HC in 35years	M$	449.912
PV of energy consumed in CC	M$	147.177
PV of energy consumed in HC	M$	132.152
PV of energy expenditure if adoptiong HC for next 35years	M$	-15.025
WATER STRESS LEVEL(% of renewable resource used)		37%

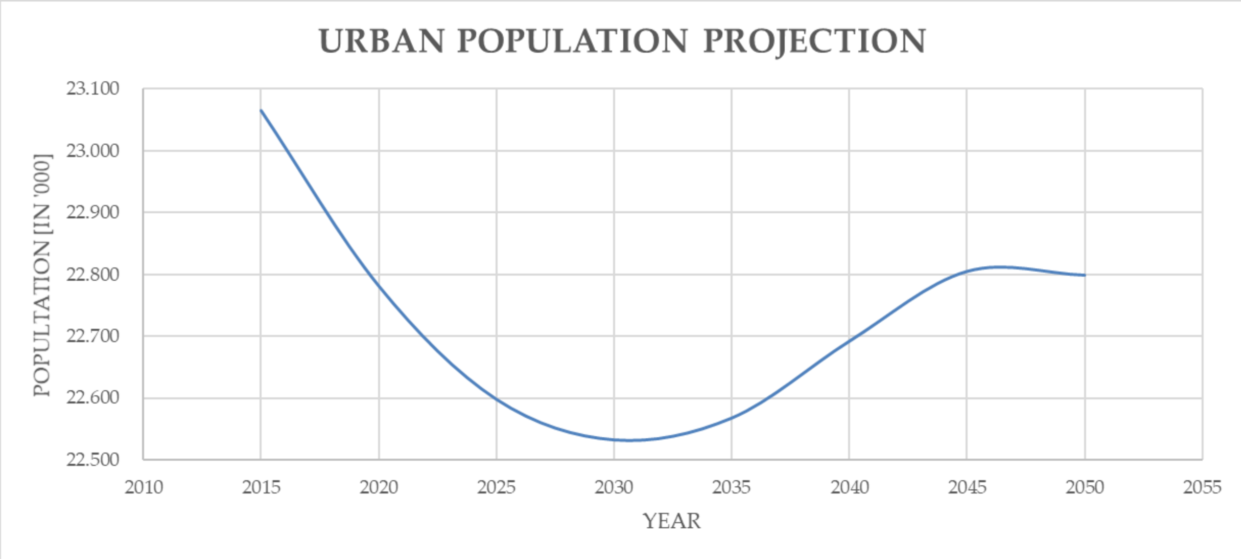
EASTERN EUROPE





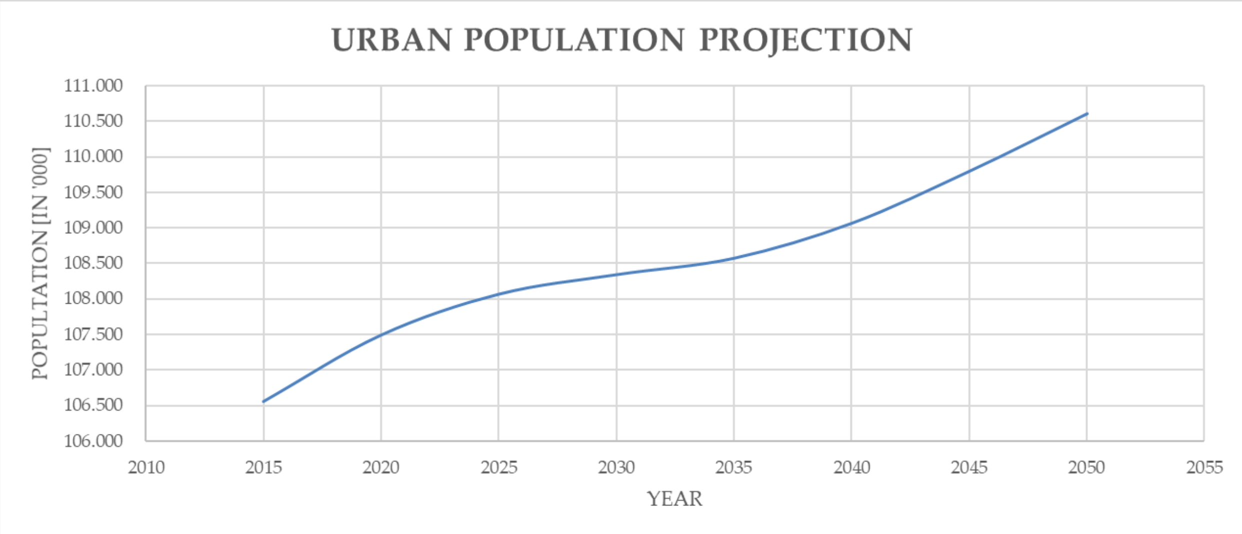
EASTERN EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,24
min WATER price Growth rate for NPV>=0		10%
min ENERGY PRICE for NPV>=0	$	3,89
min ENERGY price Growth rate for NPV>=0		5%
min 9m3/day treatment unit price	$	-5.638
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		29,84
avg actual domestic demand 2015-2050 HC [km3/year]		20,72
DELTA		-31%
avg actual energy demand in CC [GWh/year]		32.337
avg actual energy demand in HC [GWh/year]		30.945
DELTA		-4%
PV of water lost in CC	M$	-134.340
PV of water lost in HC	M$	-93.335
PV of water savings with HC in 35years	M$	41.005
PV of energy consumed in CC	M$	18.247
PV of energy consumed in HC	M$	17.482
PV of energy expenditure if adoptiong HC for next 35years	M$	-764
WATER STRESS LEVEL(% of renewable resource used)		8%

EASTERN EUROPE – POLAND



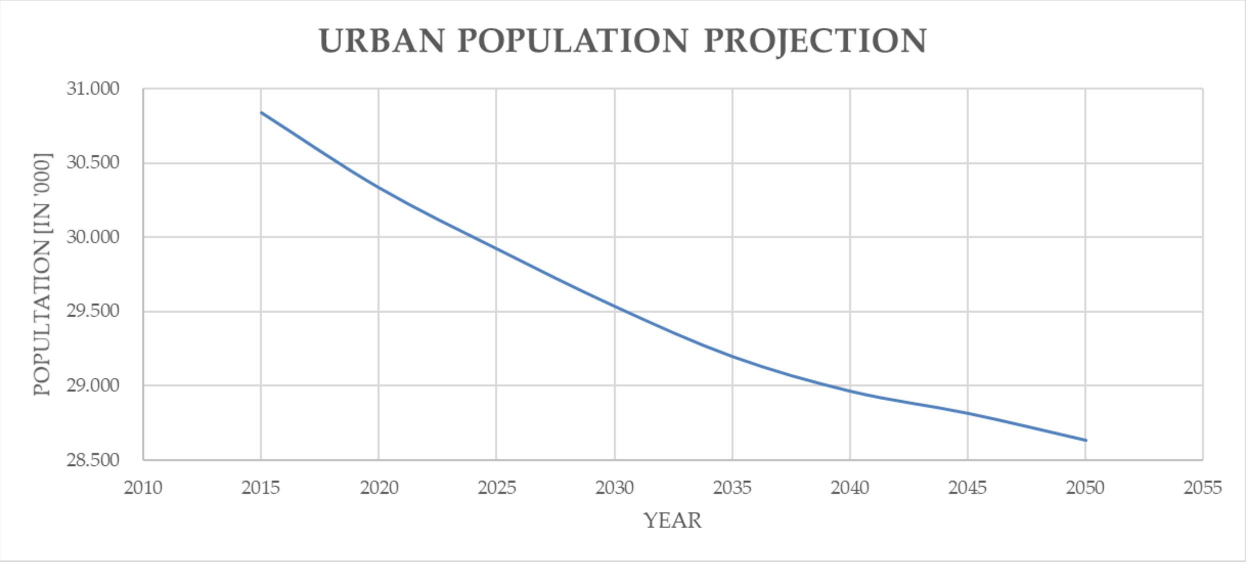
POLAND RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,34
min WATER price Growth rate for NPV>=0		-3%
min ENERGY PRICE for NPV>=0	$	-3,69
min ENERGY price Growth rate for NPV>=0		-269%
min 9m3/day treatment unit price	$	44.568
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		3,55
avg actual domestic demand 2015-2050 HC [km^3/year]		2,46
DELTA		-31%
avg actual energy demand in CC [GWh/year]		3.930
avg actual energy demand in HC [GWh/year]		3.825
DELTA		-3%
PV of water lost in CC	M$	-32.931
PV of water lost in HC	M$	-22.875
PV of water savings with HC in 35years	M$	10.056
PV of energy consumed in CC	M$	3.606
PV of energy consumed in HC	M$	3.509
PV of energy expenditure if adoptiong HC for next 35years	M$	-97
WATER STRESS LEVEL(% of renewable water resource used)		25%

EASTERN EUROPE – RUSSIAN FEDERATION



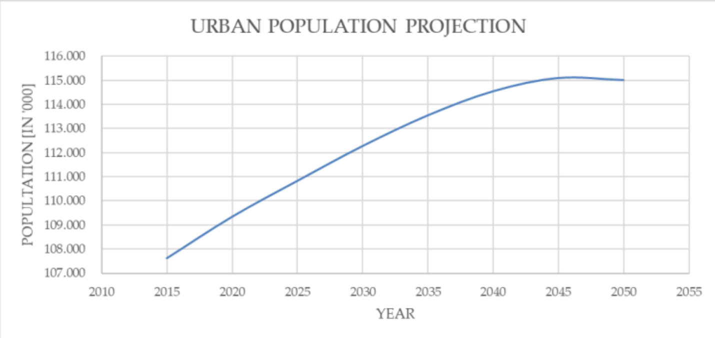
RUSSIAN FEDERATION RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,28
min WATER price Growth rate for NPV>=0		12%
min ENERGY PRICE for NPV>=0	$	5,89
min ENERGY price Growth rate for NPV>=0		52%
min 9m3/day treatment unit price	$	-13.846
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		15,70
avg actual domestic demand 2015-2050 HC [km^3/year]		10,90
DELTA		-31%
avg actual energy demand in CC [GWh/year]		17.120
avg actual energy demand in HC [GWh/year]		16.460
DELTA		-4%
PV of water lost in CC	M$	-54.375
PV of water lost in HC	M$	-37.774
PV of water savings with HC in 35years	M$	16.601
PV of energy consumed in CC	M$	8.299
PV of energy consumed in HC	M$	7.978
PV of energy expenditure if adoptiong HC for next 35years	M$	-321
WATER STRESS LEVEL(% of renewable water resource used)		2%

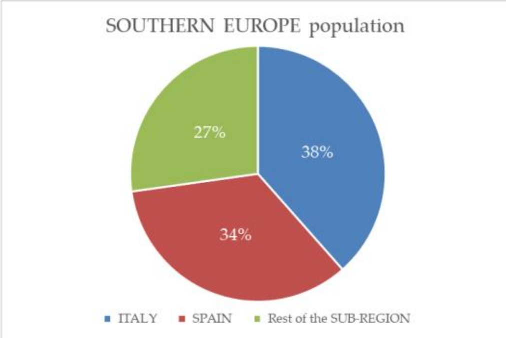
EASTERN EUROPE – UKRAINE



UKRAINE RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,05
min WATER price Growth rate for NPV>=0		12%
min ENERGY PRICE for NPV>=0	$	2,64
min ENERGY price Growth rate for NPV>=0		46%
min 9m3/day treatment unit price	$	-14.831
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		4,32
avg actual domestic demand 2015-2050 HC [km^3/year]		3,00
DELTA		-30%
avg actual energy demand in CC [GWh/year]		4.491
avg actual energy demand in HC [GWh/year]		4.158
DELTA		-7%
PV of water lost in CC	M$	-18.803
PV of water lost in HC	M$	-13.072
PV of water savings with HC in 35years	M$	5.731
PV of energy consumed in CC	M$	2.507
PV of energy consumed in HC	M$	2.321
PV of energy expenditure if adoptiong HC for next 35years	M$	-186
WATER STRESS LEVEL(% of renewable water resource used)		16%

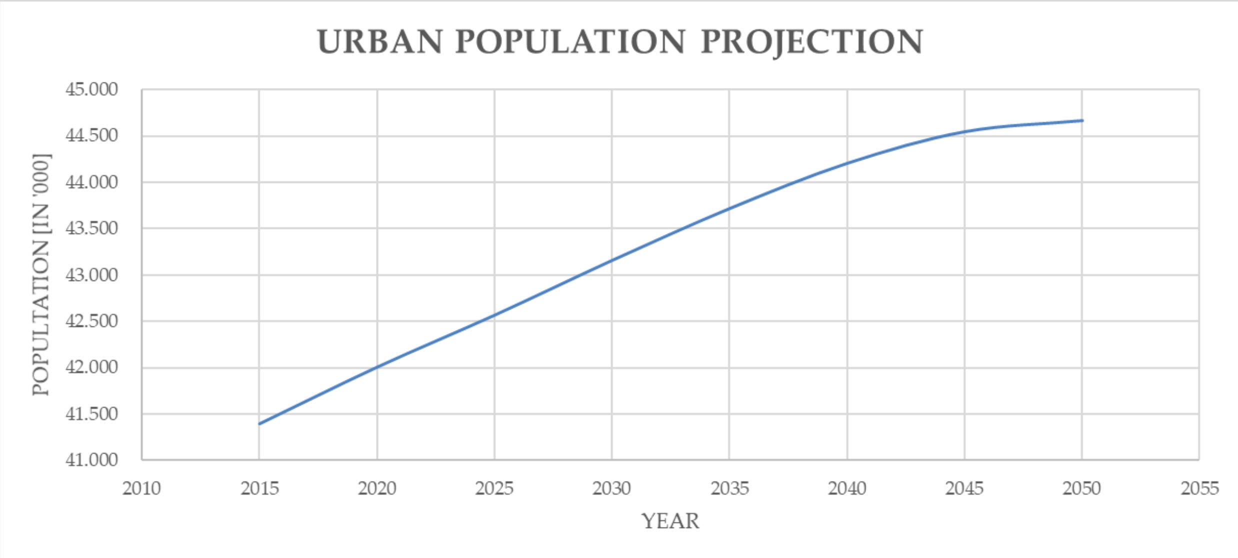
SOUTHERN EUROPE





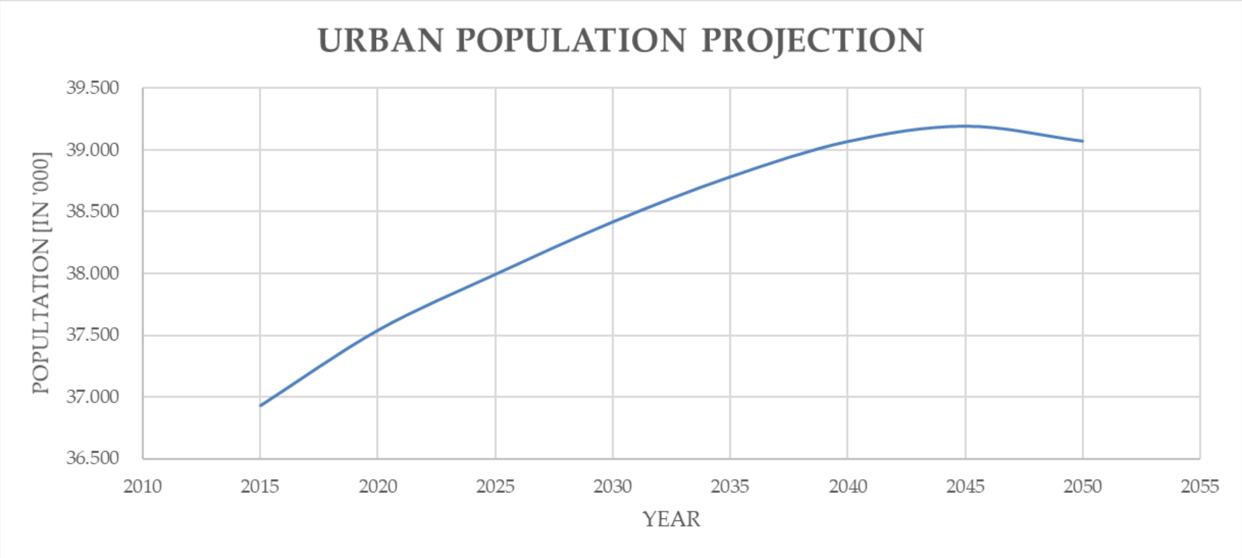
SOUTHERN EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	0,98
min WATER price Growth rate for NPV>=0		-15%
min ENERGY PRICE for NPV>=0	$	-3,43
min ENERGY price Growth rate for NPV>=0		-261%
min 9m3/day treatment unit price	$	130.058
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		22,68
avg actual domestic demand 2015-2050 HC [km3/year]		15,77
DELTA		-30%
avg actual energy demand in CC [GWh/year]		28.433
avg actual energy demand in HC [GWh/year]		25.186
DELTA		-11%
PV of water lost in CC	M$	-697.419
PV of water lost in HC	M$	-484.784
PV of water savings with HC in 35years	M$	212.635
PV of energy consumed in CC	M$	73.179
PV of energy consumed in HC	M$	64.987
PV of energy expenditure if adoptiong HC for next 35years	M$	-8.192
WATER STRESS LEVEL(% of renewable resource used)		128%

SOUTHERN EUROPE – ITALY



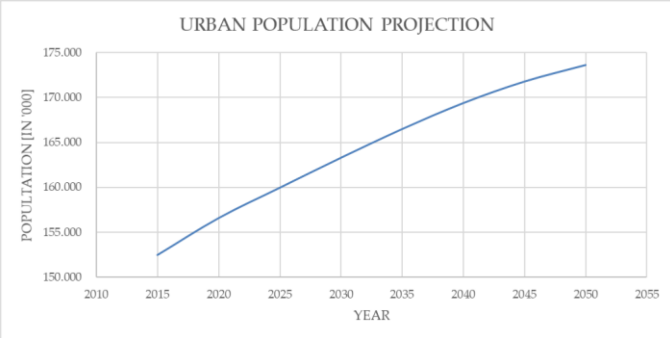
ITALY RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,76
min WATER price Growth rate for NPV>=0		-22%
min ENERGY PRICE for NPV>=0	$	-5,65
min ENERGY price Growth rate for NPV>=0		-269%
min 9m3/day treatment unit price	$	189.617
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		10,20
avg actual domestic demand 2015-2050 HC [km^3/year]		7,09
DELTA		-31%
avg actual energy demand in CC [GWh/year]		10.149
avg actual energy demand in HC [GWh/year]		9.035
DELTA		-11%
PV of water lost in CC	M$	-443.778
PV of water lost in HC	M$	-308.456
PV of water savings with HC in 35years	M$	135.322
PV of energy consumed in CC	M$	39.842
PV of energy consumed in HC	M$	35.469
PV of energy expenditure if adoptiong HC for next 35years	M$	-4.373
WATER STRESS LEVEL(% of renewable water resource used)		107%

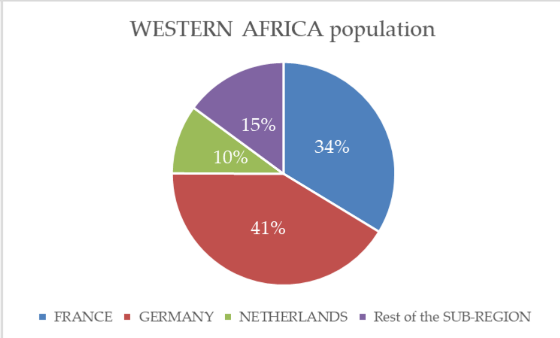
SOUTHERN EUROPE – SPAIN



SPAIN RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,22
min WATER price Growth rate for NPV>=0		-7%
min ENERGY PRICE for NPV>=0	$	-0,94
min ENERGY price Growth rate for NPV>=0		-252%
min 9m3/day treatment unit price	$	63.305
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		6,30
avg actual domestic demand 2015-2050 HC [km^3/year]		4,38
DELTA		-30%
avg actual energy demand in CC [GWh/year]		10.546
avg actual energy demand in HC [GWh/year]		9.297
DELTA		-12%
PV of water lost in CC	M$	-63.824
PV of water lost in HC	M$	-44.384
PV of water savings with HC in 35years	M$	19.439
PV of energy consumed in CC	M$	13.420
PV of energy consumed in HC	M$	11.831
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.589
WATER STRESS LEVEL(% of renewable water resource used)		72%

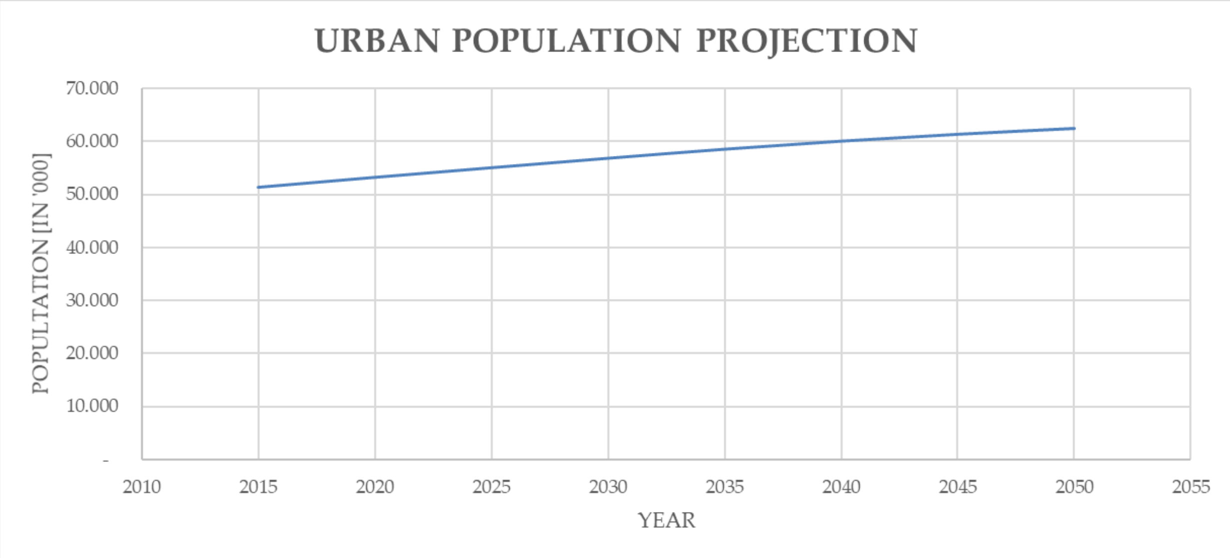
WESTERN EUROPE





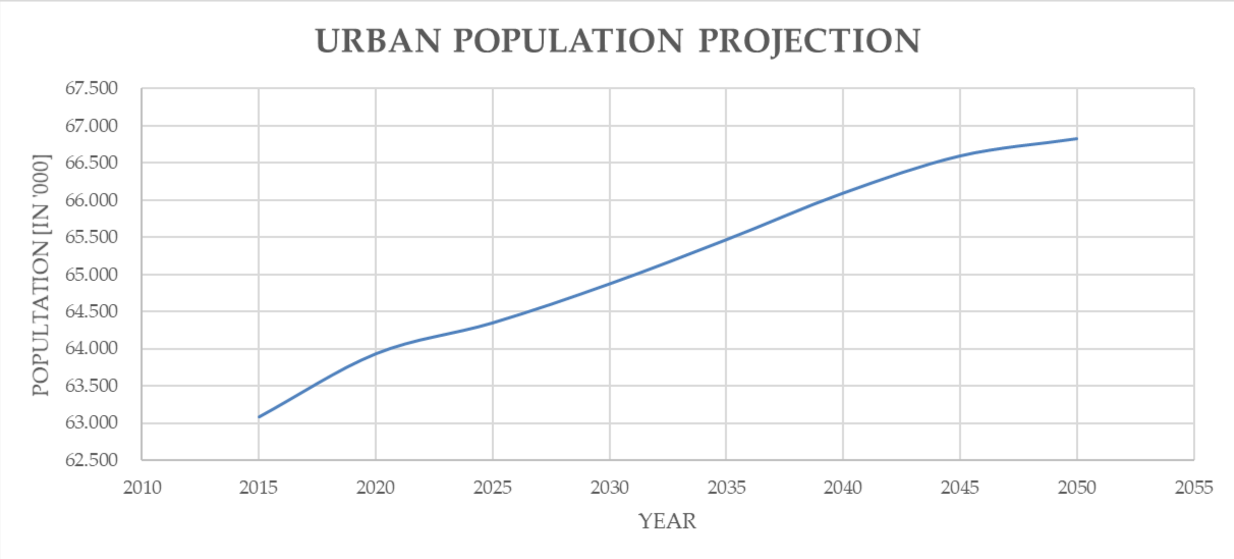
WESTERN EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	1,15
min WATER price Growth rate for NPV>=0		-10%
min ENERGY PRICE for NPV>=0	$	-2,36
min ENERGY price Growth rate for NPV>=0		-227%
min 9m3/day treatment unit price	$	78.553
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		14,49
avg actual domestic demand 2015-2050 HC [km3/year]		10,06
DELTA		-36%
avg actual energy demand in CC [GWh/year]		24.086
avg actual energy demand in HC [GWh/year]		21.297
DELTA		-6%
PV of water lost in CC	M$	-134.430
PV of water lost in HC	M$	-93.339
PV of water savings with HC in 35years	M$	41.091
PV of energy consumed in CC	M$	21.895
PV of energy consumed in HC	M$	19.626
PV of energy expenditure if adoptiong HC for next 35years	M$	-2.268
WATER STRESS LEVEL(% of renewable resource used)		21%

WESTERN EUROPE – FRANCE



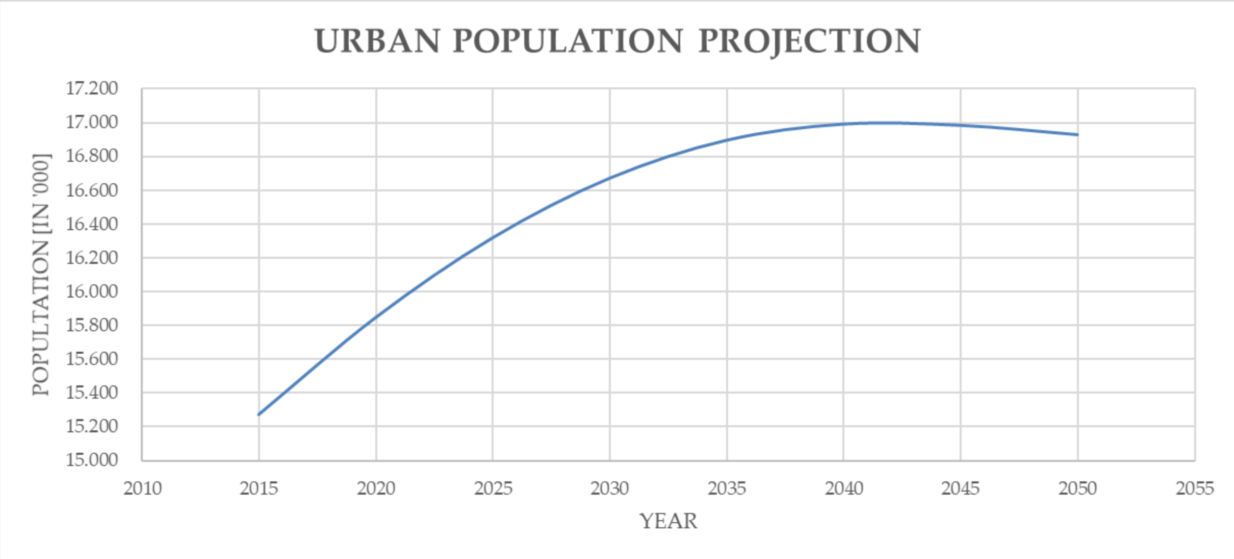
FRANCE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,29
min WATER price Growth rate for NPV>=0		-6%
min ENERGY PRICE for NPV>=0	$	-5,07
min ENERGY price Growth rate for NPV>=0		-271%
min 9m3/day treatment unit price	$	58.425
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		6,78
avg actual domestic demand 2015-2050 HC [km^3/year]		4,70
DELTA		-31%
avg actual energy demand in CC [GWh/year]		7.425
avg actual energy demand in HC [GWh/year]		7.164
DELTA		-4%
PV of water lost in CC	M$	-85.188
PV of water lost in HC	M$	-59.128
PV of water savings with HC in 35years	M$	26.061
PV of energy consumed in CC	M$	9.186
PV of energy consumed in HC	M$	8.862
PV of energy expenditure if adoptiong HC for next 35years	M$	-323
WATER STRESS LEVEL(% of renewable water resource used)		24%

WESTERN EUROPE – GERMANY



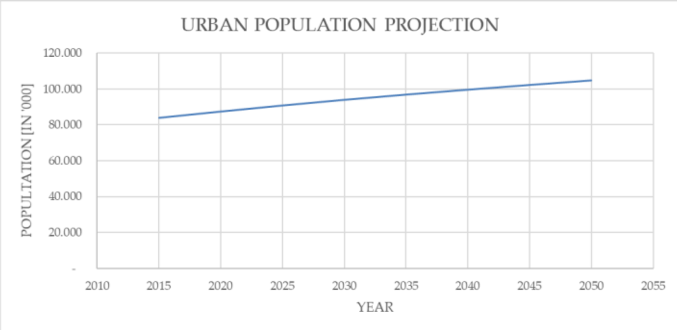
GERMANY RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,96
min WATER price Growth rate for NPV>=0		-17%
min ENERGY PRICE for NPV>=0	$	-0,81
min ENERGY price Growth rate for NPV>=0		-248%
min 9m3/day treatment unit price	$	107.807
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		4,06
avg actual domestic demand 2015-2050 HC [km^3/year]		2,82
DELTA		-31%
avg actual energy demand in CC [GWh/year]		11.225
avg actual energy demand in HC [GWh/year]		9.209
DELTA		-18%
PV of water lost in CC	M$	-25.683
PV of water lost in HC	M$	-17.850
PV of water savings with HC in 35years	M$	7.833
PV of energy consumed in CC	M$	8.742
PV of energy consumed in HC	M$	7.172
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.570
WATER STRESS LEVEL(% of renewable water resource used)		20%

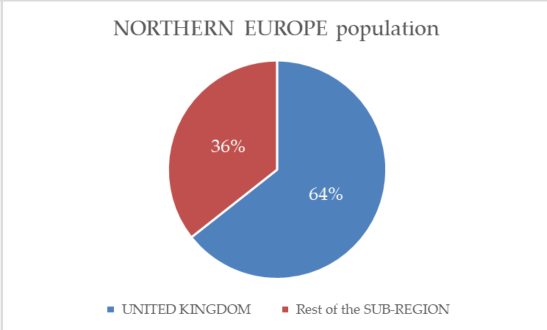
WESTERN EUROPE – NETHERLANDS



NETHERLANDS RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,51
min WATER price Growth rate for NPV>=0		0%
min ENERGY PRICE for NPV>=0	$	0,33
min ENERGY price Growth rate for NPV>=0		4%
min 9m3/day treatment unit price	$	25.397
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,48
avg actual domestic demand 2015-2050 HC [km^3/year]		1,03
DELTA		-30%
avg actual energy demand in CC [GWh/year]		1.843
avg actual energy demand in HC [GWh/year]		1.746
DELTA		-5%
PV of water lost in CC	M$	-3.501
PV of water lost in HC	M$	-2.434
PV of water savings with HC in 35years	M$	1.066
PV of energy consumed in CC	M$	700
PV of energy consumed in HC	M$	664
PV of energy expenditure if adoptiong HC for next 35years	M$	-37
WATER STRESS LEVEL(% of renewable water resource used)		15%

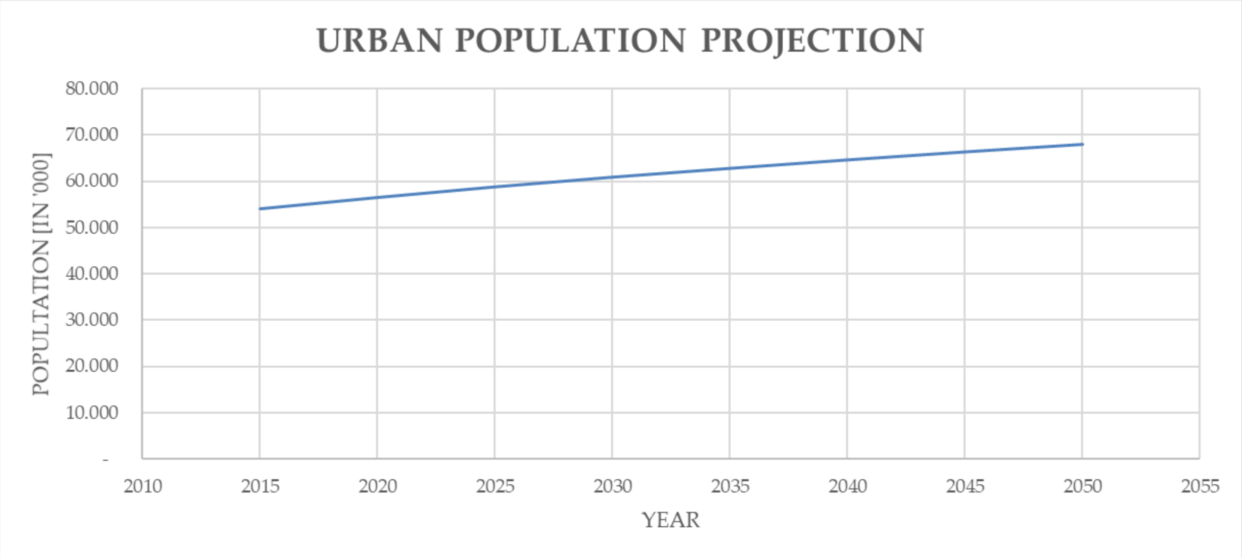
NORTHERN EUROPE





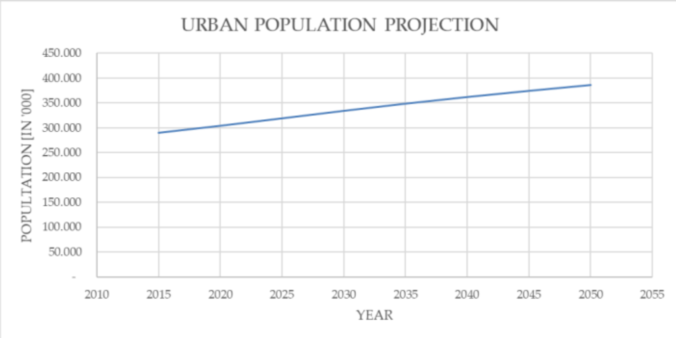
NORTHERN EUROPE RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	1,18
min WATER price Growth rate for NPV>=0		-25%
min ENERGY PRICE for NPV>=0	$	-7,07
min ENERGY price Growth rate for NPV>=0		-272%
min 9m3/day treatment unit price	$	231.450
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		14,31
avg actual domestic demand 2015-2050 HC [km3/year]		9,91
DELTA		-31%
avg actual energy demand in CC [GWh/year]		21.706
avg actual energy demand in HC [GWh/year]		19.271
DELTA		-11%
PV of water lost in CC	M$	-506.520
PV of water lost in HC	M$	-351.339
PV of water savings with HC in 35years	M$	155.181
PV of energy consumed in CC	M$	33.857
PV of energy consumed in HC	M$	30.057
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.800
WATER STRESS LEVEL(% of renewable resource used)		16%

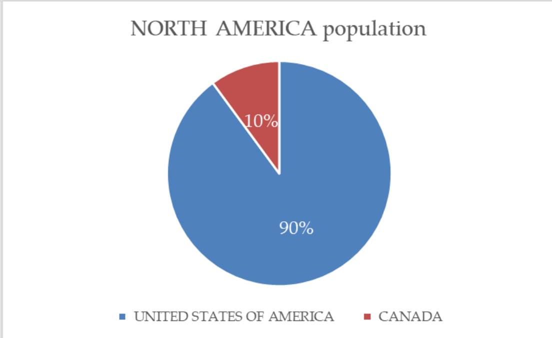
NORTHERN EUROPE – UNITED KINGDOM



UNITED KINGDOM RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,18
min WATER price Growth rate for NPV>=0		-25%
min ENERGY PRICE for NPV>=0	$	-7,07
min ENERGY price Growth rate for NPV>=0		-272%
min 9m3/day treatment unit price	$	231.450
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		9,21
avg actual domestic demand 2015-2050 HC [km^3/year]		6,38
DELTA		-31%
avg actual energy demand in CC [GWh/year]		13.972
avg actual energy demand in HC [GWh/year]		12.405
DELTA		-11%
PV of water lost in CC	M$	-326.056
PV of water lost in HC	M$	-226.163
PV of water savings with HC in 35years	M$	99.893
PV of energy consumed in CC	M$	21.794
PV of energy consumed in HC	M$	19.348
PV of energy expenditure if adoptiong HC for next 35years	M$	-2.446
WATER STRESS LEVEL(% of renewable water resource used)		16%

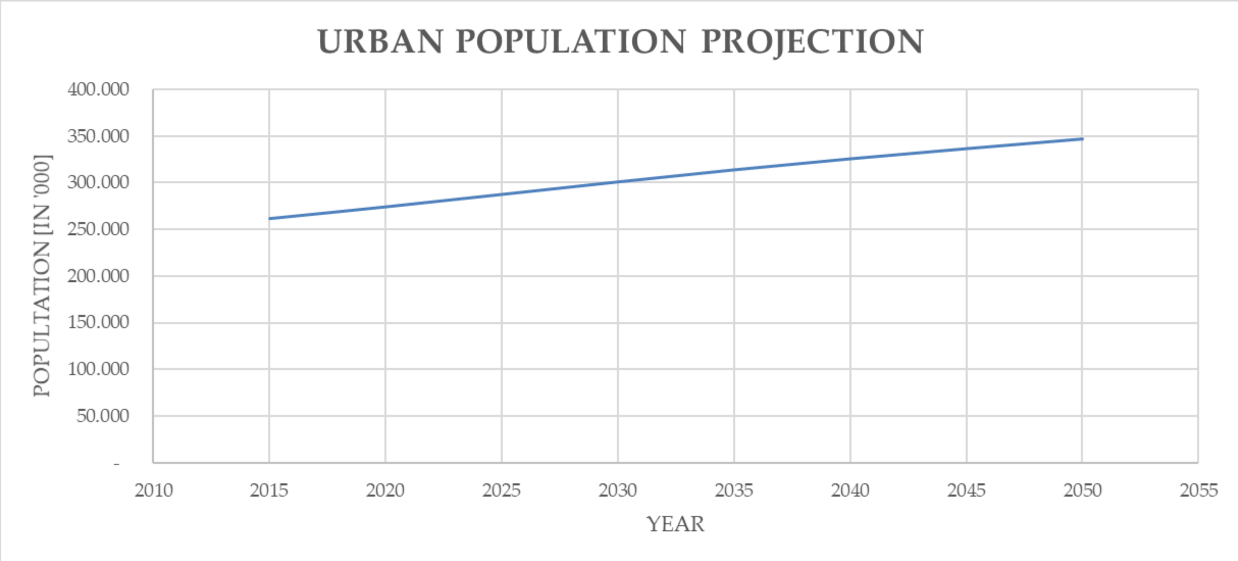
NORTH AMERICA





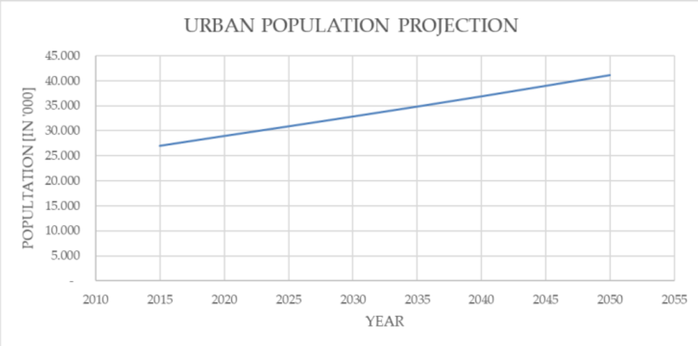
NORTH AMERICA RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,35
min WATER price Growth rate for NPV>=0		-1%
min ENERGY PRICE for NPV>=0	$	-0,53
min ENERGY price Growth rate for NPV>=0		-252%
min 9m3/day treatment unit price	$	33.517
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		90,64
avg actual domestic demand 2015-2050 HC [km3/year]		62,74
DELTA		-31%
avg actual energy demand in CC [GWh/year]		112.790
avg actual energy demand in HC [GWh/year]		106.229
DELTA		-6%
PV of water lost in CC	M$	-753.170
PV of water lost in HC	M$	-521.962
PV of water savings with HC in 35years	M$	231.207
PV of energy consumed in CC	M$	87.451
PV of energy consumed in HC	M$	82.351
PV of energy expenditure if adoptiong HC for next 35years	M$	-5.100
WATER STRESS LEVEL(% of renewable resource used)		23%

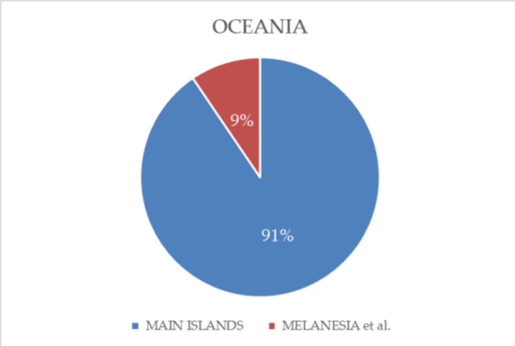
NORTH AMERICA – UNITED STATES OF AMERICA



UNITED STATES OF AMERICA RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,35
min WATER price Growth rate for NPV>=0		-1%
min ENERGY PRICE for NPV>=0	$	-0,53
min ENERGY price Growth rate for NPV>=0		-252%
min 9m3/day treatment unit price	$	33.517
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		81,49
avg actual domestic demand 2015-2050 HC [km^3/year]		56,41
DELTA		-31%
avg actual energy demand in CC [GWh/year]		101.408
avg actual energy demand in HC [GWh/year]		95.509
DELTA		-6%
PV of water lost in CC	M$	-677.161
PV of water lost in HC	M$	-469.286
PV of water savings with HC in 35years	M$	207.874
PV of energy consumed in CC	M$	78.625
PV of energy consumed in HC	M$	74.040
PV of energy expenditure if adoptiong HC for next 35years	M$	-4.586
WATER STRESS LEVEL(% of renewable water resource used)		23%

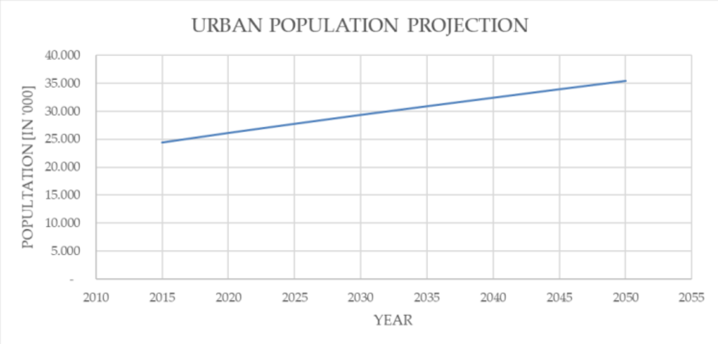
OCEANIA

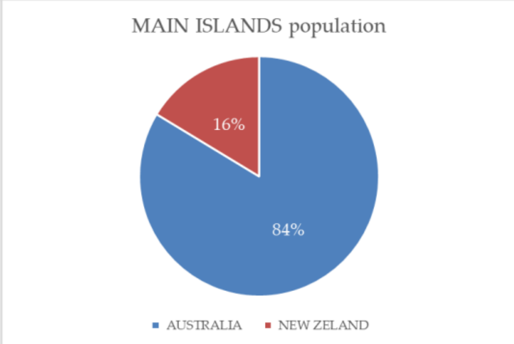




OCEANIA RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	1,31
min WATER price Growth rate for NPV>=0		-6%
min ENERGY PRICE for NPV>=0	$	-2,94
min ENERGY price Growth rate for NPV>=0		-236%
min 9m3/day treatment unit price	$	72.685
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		12,43
avg actual domestic demand 2015-2050 HC [km3/year]		8,57
DELTA		-31%
avg actual energy demand in CC [GWh/year]		17.947
avg actual energy demand in HC [GWh/year]		16.559
DELTA		-8%
PV of water lost in CC	M$	-131.983
PV of water lost in HC	M$	-91.227
PV of water savings with HC in 35years	M$	40.756
PV of energy consumed in CC	M$	17.706
PV of energy consumed in HC	M$	16.369
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.336
WATER STRESS LEVEL(% of renewable resource used)		21%

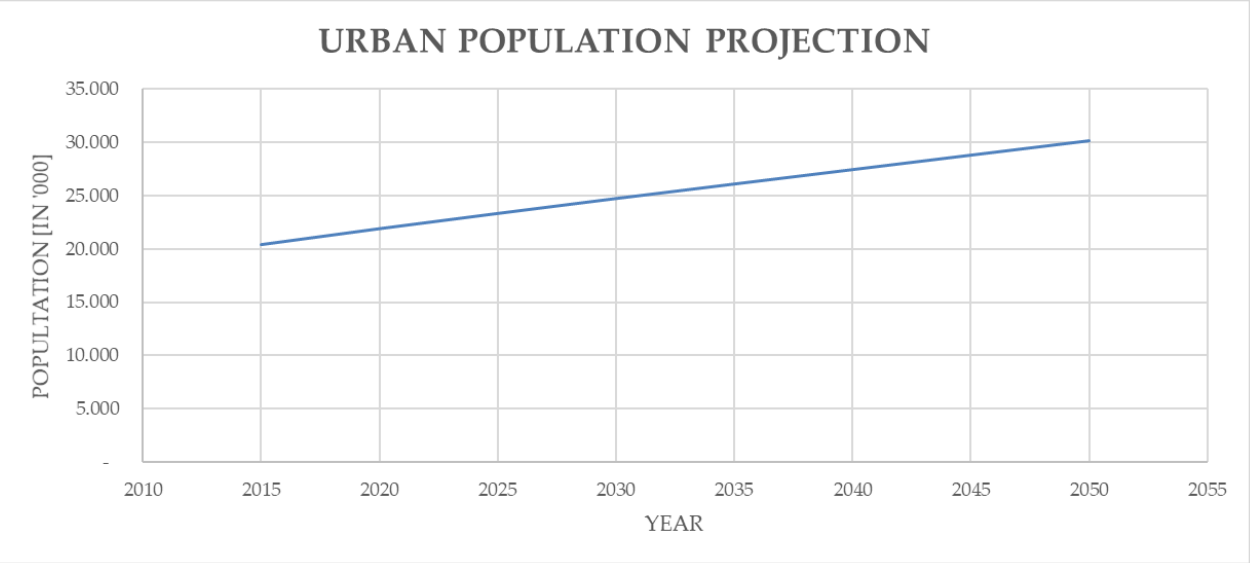
MAIN ISLANDS





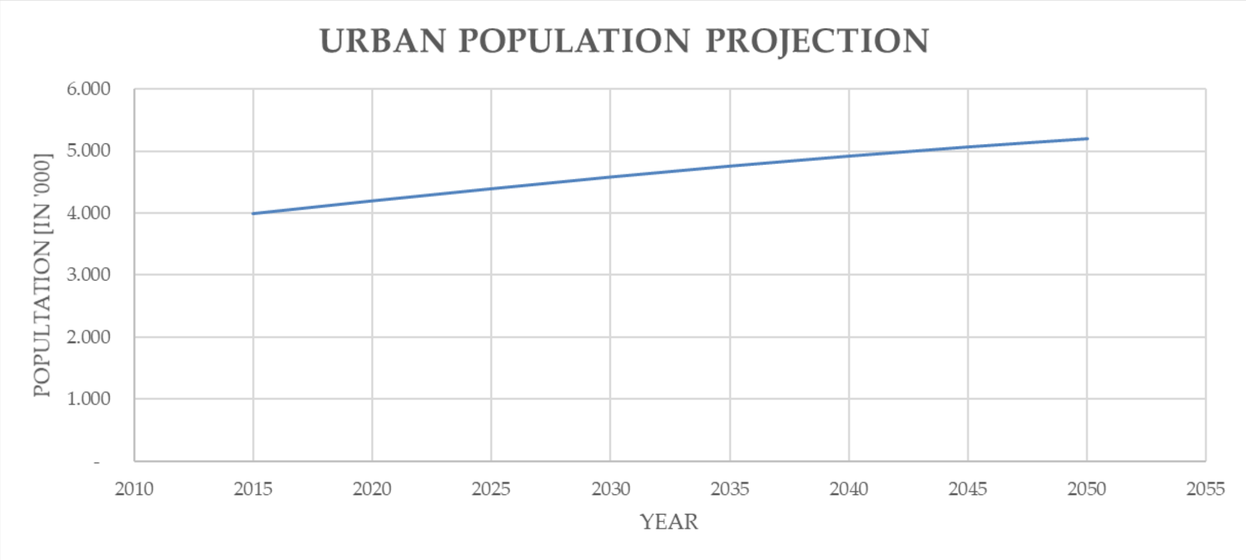
MAIN ISLANDS RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	1,36
min WATER price Growth rate for NPV>=0		-9%
min ENERGY PRICE for NPV>=0	$	-3,50
min ENERGY price Growth rate for NPV>=0		-265%
min 9m3/day treatment unit price	$	83.400
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		13,72
avg actual domestic demand 2015-2050 HC [km3/year]		9,46
DELTA		-31%
avg actual energy demand in CC [GWh/year]		19.814
avg actual energy demand in HC [GWh/year]		18.282
DELTA		-8%
PV of water lost in CC	M$	-131.741
PV of water lost in HC	M$	-91.059
PV of water savings with HC in 35years	M$	40.681
PV of energy consumed in CC	M$	17.389
PV of energy consumed in HC	M$	16.085
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.304
WATER STRESS LEVEL(% of renewable resource used)		24%

MAIN ISLANDS – AUSTRALIA



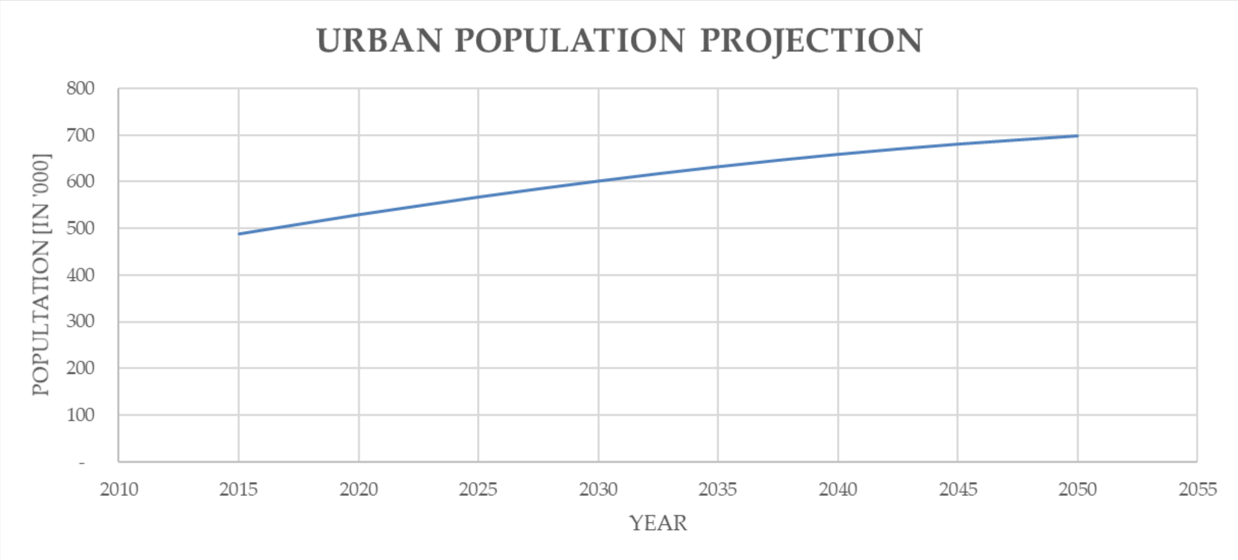
AUSTRALIA RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,38
min WATER price Growth rate for NPV>=0		-10%
min ENERGY PRICE for NPV>=0	$	-3,41
min ENERGY price Growth rate for NPV>=0		-264%
min 9m3/day treatment unit price	$	89.775
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		12,50
avg actual domestic demand 2015-2050 HC [km^3/year]		8,62
DELTA		-31%
avg actual energy demand in CC [GWh/year]		18.532
avg actual energy demand in HC [GWh/year]		17.042
DELTA		-8%
PV of water lost in CC	M$	-116.504
PV of water lost in HC	M$	-80.531
PV of water savings with HC in 35years	M$	35.973
PV of energy consumed in CC	M$	15.422
PV of energy consumed in HC	M$	14.182
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.241
WATER STRESS LEVEL(% of renewable water resource used)		28%

MAIN ISLANDS – NEW ZEALAND



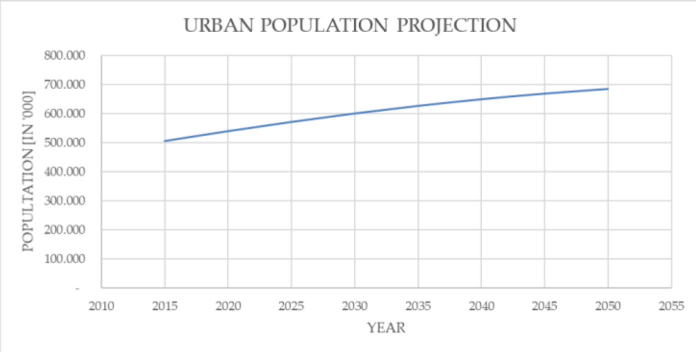
NEW ZEALAND RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,24
min WATER price Growth rate for NPV>=0		-4%
min ENERGY PRICE for NPV>=0	$	-3,99
min ENERGY price Growth rate for NPV>=0		-267%
min 9m3/day treatment unit price	$	50.762
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,22
avg actual domestic demand 2015-2050 HC [km^3/year]		0,84
DELTA		-31%
avg actual energy demand in CC [GWh/year]		1.282
avg actual energy demand in HC [GWh/year]		1.240
DELTA		-3%
PV of water lost in CC	M$	-15.237
PV of water lost in HC	M$	-10.529
PV of water savings with HC in 35years	M$	4.709
PV of energy consumed in CC	M$	1.967
PV of energy consumed in HC	M$	1.903
PV of energy expenditure if adoptiong HC for next 35years	M$	-64
WATER STRESS LEVEL(% of renewable water resource used)		2%

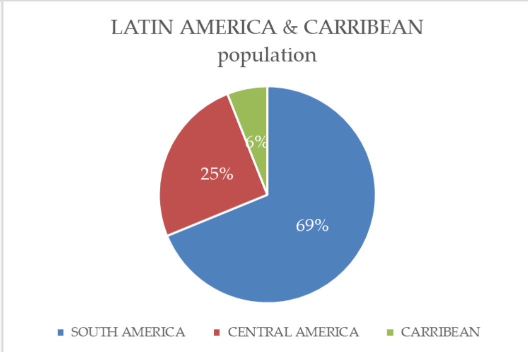
MELANESIA – FIJI



FIJI RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,86
min WATER price Growth rate for NPV>=0		25%
min ENERGY PRICE for NPV>=0	$	2,40
min ENERGY price Growth rate for NPV>=0		34%
min 9m3/day treatment unit price	$	-29.487
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		0,04
avg actual domestic demand 2015-2050 HC [km^3/year]		0,03
DELTA		-31%
avg actual energy demand in CC [GWh/year]		36
avg actual energy demand in HC [GWh/year]		33
DELTA		-10%
PV of water lost in CC	M$	-62
PV of water lost in HC	M$	-43
PV of water savings with HC in 35years	M$	19
PV of energy consumed in CC	M$	81
PV of energy consumed in HC	M$	73
PV of energy expenditure if adoptiong HC for next 35years	M$	-8
WATER STRESS LEVEL(% of renewable water resource used)		1%

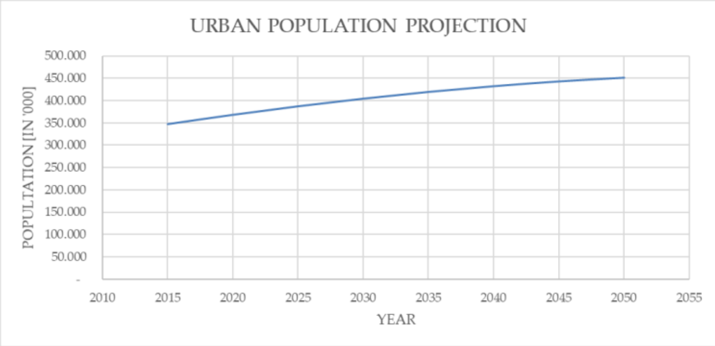
LATIN AMERICA & CARRIBEAN

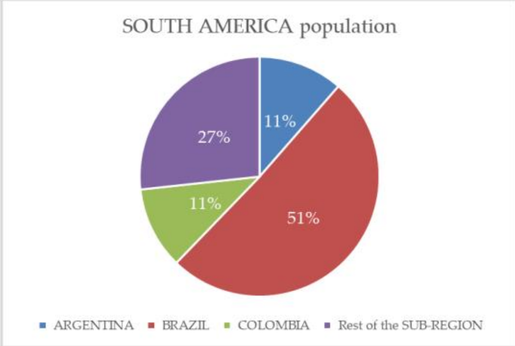




LATIN AMERICA & CARRIBEAN RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	YES	
min WATER PRICE for NPV>=0	$	0,97
min WATER price Growth rate for NPV>=0		5%
min ENERGY PRICE for NPV>=0	$	0,59
min ENERGY price Growth rate for NPV>=0		-48%
min 9m3/day treatment unit price	$	10.899
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		45,10
avg actual domestic demand 2015-2050 HC [km3/year]		31,28
DELTA		-31%
avg actual energy demand in CC [GWh/year]		45.179
avg actual energy demand in HC [GWh/year]		40.487
DELTA		-10%
PV of water lost in CC	M$	-1.514.425
PV of water lost in HC	M$	-1.051.330
PV of water savings with HC in 35years	M$	463.096
PV of energy consumed in CC	M$	235.231
PV of energy consumed in HC	M$	209.082
PV of energy expenditure if adoptiong HC for next 35years	M$	-26.148
WATER STRESS LEVEL(% of renewable resource used)		11%

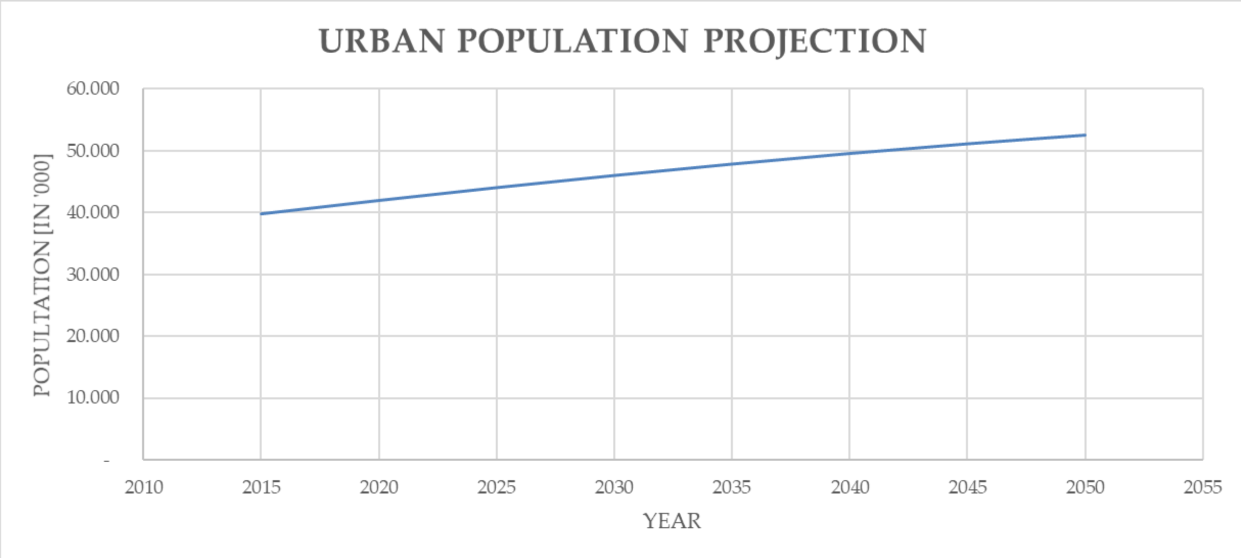
SOUTH AMERICA





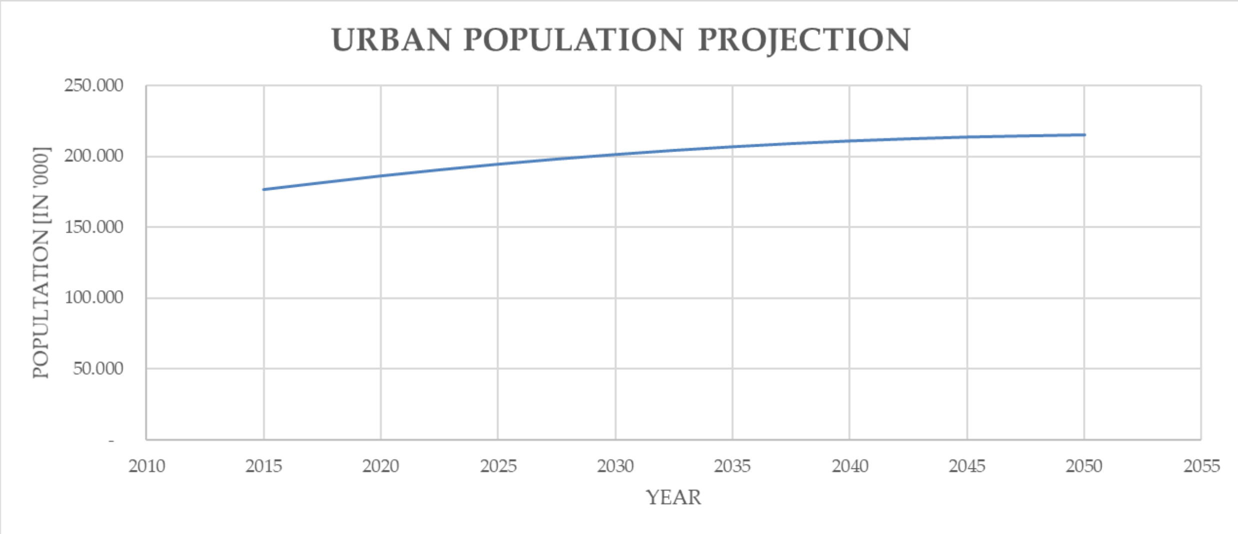
SOUTH AMERICA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	0,91
min WATER price Growth rate for NPV>=0		6%
min ENERGY PRICE for NPV>=0	$	1,34
min ENERGY price Growth rate for NPV>=0		25%
min 9m3/day treatment unit price	$	1.954
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		57,50
avg actual domestic demand 2015-2050 HC [km3/year]		39,89
DELTA		-31%
avg actual energy demand in CC [GWh/year]		57.239
avg actual energy demand in HC [GWh/year]		51.006
DELTA		-11%
PV of water lost in CC	M$	-471.498
PV of water lost in HC	M$	-327.276
PV of water savings with HC in 35years	M$	144.222
PV of energy consumed in CC	M$	130.139
PV of energy consumed in HC	M$	115.702
PV of energy expenditure if adoptiong HC for next 35years	M$	-14.437
WATER STRESS LEVEL(% of renewable resource used)		2%

SOUTH AMERICA – ARGENTINA



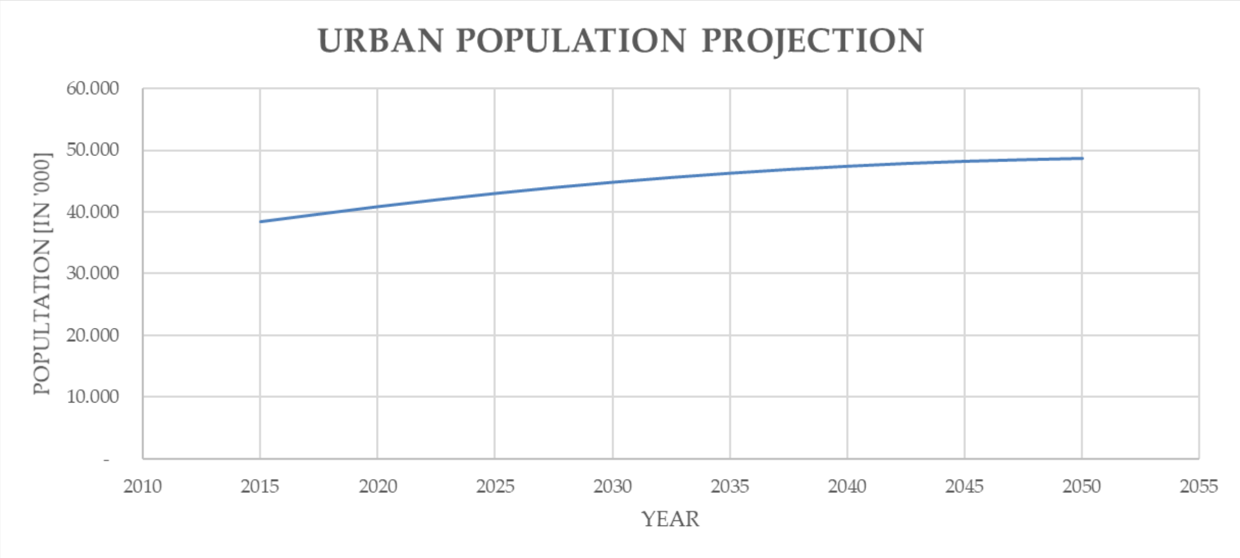
ARGENTINA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,92
min WATER price Growth rate for NPV>=0		6%
min ENERGY PRICE for NPV>=0	$	1,14
min ENERGY price Growth rate for NPV>=0		30%
min 9m3/day treatment unit price	$	3.628
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		10,04
avg actual domestic demand 2015-2050 HC [km^3/year]		6,95
DELTA		-31%
avg actual energy demand in CC [GWh/year]		10.090
avg actual energy demand in HC [GWh/year]		9.066
DELTA		-10%
PV of water lost in CC	M$	-85.935
PV of water lost in HC	M$	-59.518
PV of water savings with HC in 35years	M$	26.417
PV of energy consumed in CC	M$	12.943
PV of energy consumed in HC	M$	11.624
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.320
WATER STRESS LEVEL(% of renewable water resource used)		7%

SOUTH AMERICA – BRAZIL



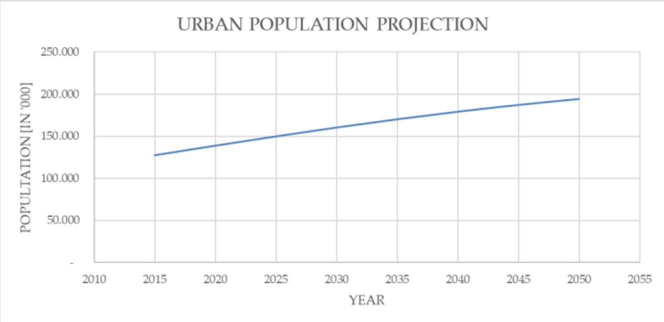
BRAZIL RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/$m^3$]	$	0,94
min WATER price Growth rate for NPV>=0		6%
min ENERGY PRICE for NPV>=0	$	1,45
min ENERGY price Growth rate for NPV>=0		25%
min 9m3/day treatment unit price	$	2.048
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		20,95
avg actual domestic demand 2015-2050 HC [km^3/year]		14,55
DELTA		-31%
avg actual energy demand in CC [GWh/year]		21.038
avg actual energy demand in HC [GWh/year]		18.895
DELTA		-10%
PV of water lost in CC	M$	-174.976
PV of water lost in HC	M$	-121.545
PV of water savings with HC in 35years	M$	53.432
PV of energy consumed in CC	M$	54.446
PV of energy consumed in HC	M$	48.830
PV of energy expenditure if adoptiong HC for next 35years	M$	-5.617
WATER STRESS LEVEL(% of renewable water resource used)		1%

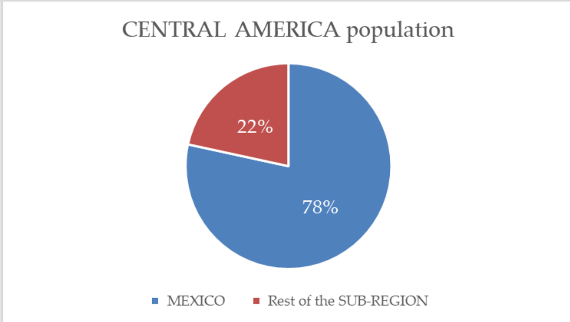
SOUTH AMERICA – COLOMBIA



COLOMBIA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,77
min WATER price Growth rate for NPV>=0		7%
min ENERGY PRICE for NPV>=0	$	1,03
min ENERGY price Growth rate for NPV>=0		23%
min 9m3/day treatment unit price	$	-202
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		11,14
avg actual domestic demand 2015-2050 HC [km^3/year]		7,74
DELTA		-31%
avg actual energy demand in CC [GWh/year]		10.817
avg actual energy demand in HC [GWh/year]		9.418
DELTA		-13%
PV of water lost in CC	M$	-84.612
PV of water lost in HC	M$	-58.771
PV of water savings with HC in 35years	M$	25.840
PV of energy consumed in CC	M$	27.979
PV of energy consumed in HC	M$	24.336
PV of energy expenditure if adoptiong HC for next 35years	M$	-3.643
WATER STRESS LEVEL(% of renewable water resource used)		1%

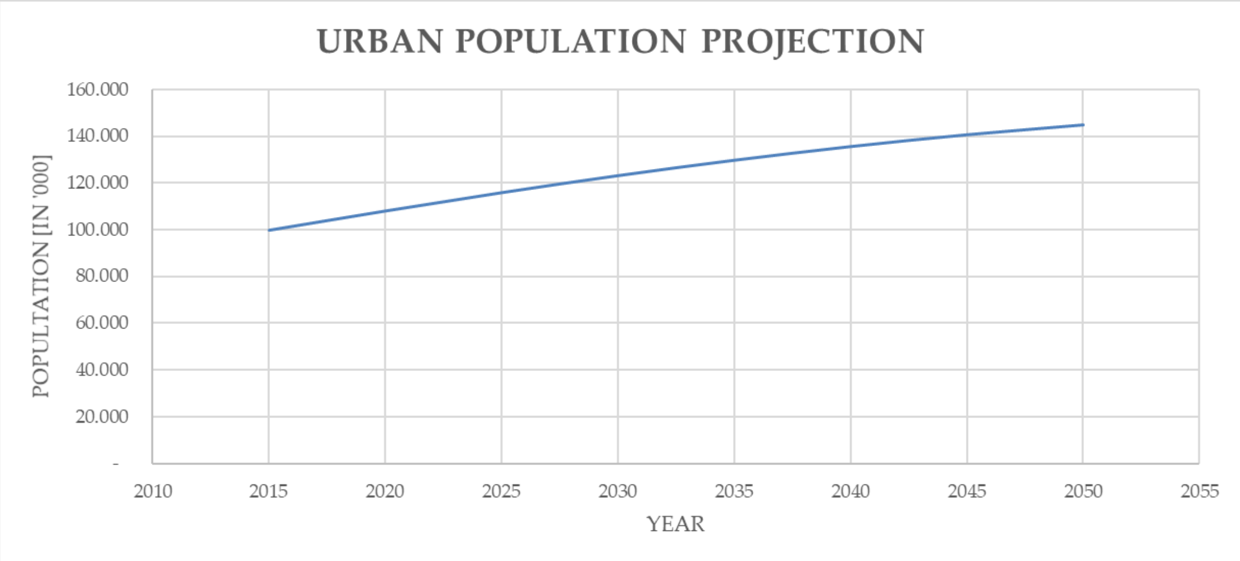
CENTRAL AMERICA





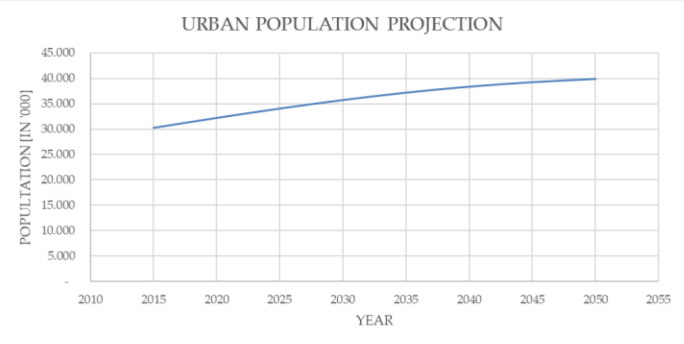
CENTRAL AMERICA RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	1,23
min WATER price Growth rate for NPV>=0		-3%
min ENERGY PRICE for NPV>=0	$	-1,56
min ENERGY price Growth rate for NPV>=0		-268%
min 9m3/day treatment unit price	$	39.787
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		20,56
avg actual domestic demand 2015-2050 HC [km3/year]		14,22
DELTA		-31%
avg actual energy demand in CC [GWh/year]		21.652
avg actual energy demand in HC [GWh/year]		20.255
DELTA		-6%
PV of water lost in CC	M$	-312.537
PV of water lost in HC	M$	-216.461
PV of water savings with HC in 35years	M$	96.076
PV of energy consumed in CC	M$	17.632
PV of energy consumed in HC	M$	16.462
PV of energy expenditure if adoptiong HC for next 35years	M$	-1.170
WATER STRESS LEVEL(% of renewable resource used)		29%

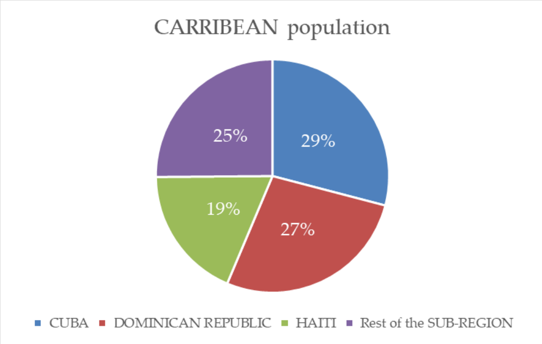
CENTRAL AMERICA – MEXICO



MEXICO RESULTS		
STATE IMPLEMENTATION	YES	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	1,23
min WATER price Growth rate for NPV>=0		-3%
min ENERGY PRICE for NPV>=0	$	-1,56
min ENERGY price Growth rate for NPV>=0		-268%
min 9m3/day treatment unit price	$	39.787
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		16,12
avg actual domestic demand 2015-2050 HC [km^3/year]		11,15
DELTA		-31%
avg actual energy demand in CC [GWh/year]		16.976
avg actual energy demand in HC [GWh/year]		15.881
DELTA		-6%
PV of water lost in CC	M$	-245.044
PV of water lost in HC	M$	-169.716
PV of water savings with HC in 35years	M$	75.328
PV of energy consumed in CC	M$	13.824
PV of energy consumed in HC	M$	12.907
PV of energy expenditure if adoptiong HC for next 35years	M$	-918
WATER STRESS LEVEL(% of renewable water resource used)		29%

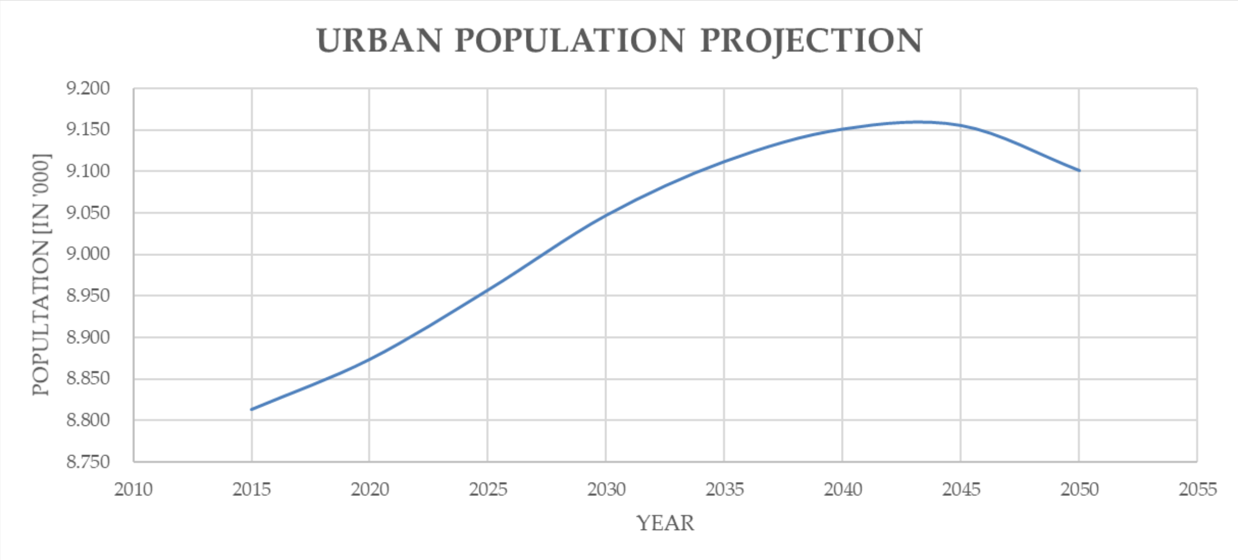
CARRIBEAN





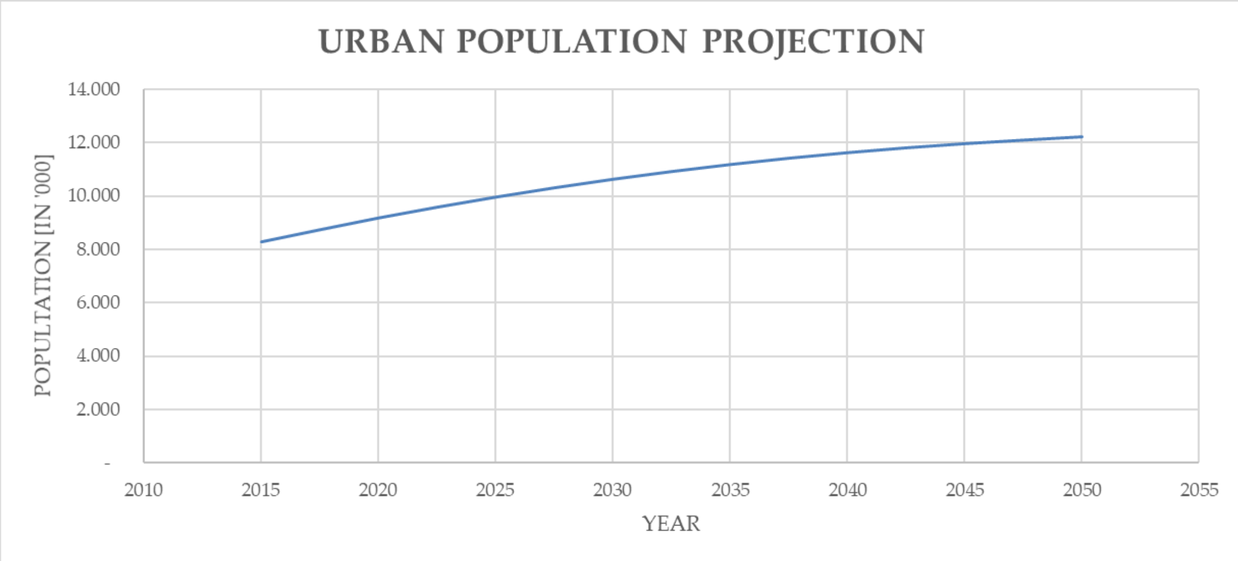
CARRIBEAN RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0	$	0,57
min WATER price Growth rate for NPV>=0		24%
min ENERGY PRICE for NPV>=0	$	1,09
min ENERGY price Growth rate for NPV>=0		29%
min 9m3/day treatment unit price	$	-7.792
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km3/year]		5,95
avg actual domestic demand 2015-2050 HC [km3/year]		4,11
DELTA		-42%
avg actual energy demand in CC [GWh/year]		5.630
avg actual energy demand in HC [GWh/year]		4.779
DELTA		-22%
PV of water lost in CC	M$	-32.971
PV of water lost in HC	M$	-22.808
PV of water savings with HC in 35years	M$	10.163
PV of energy consumed in CC	M$	14.280
PV of energy consumed in HC	M$	11.932
PV of energy expenditure if adoptiong HC for next 35years	M$	-2.348
WATER STRESS LEVEL(% of renewable resource used)		41%

CARRIBEAN – CUBA



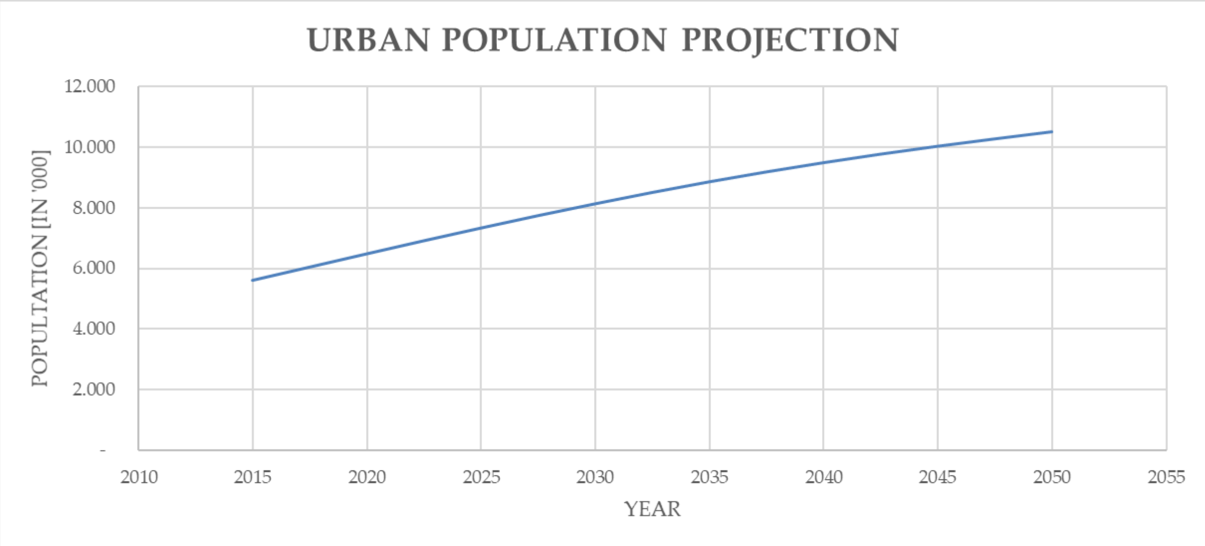
CUBA RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,82
min WATER price Growth rate for NPV>=0		51%
min ENERGY PRICE for NPV>=0	$	2,15
min ENERGY price Growth rate for NPV>=0		63%
min 9m3/day treatment unit price	$	-38.890
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		1,28
avg actual domestic demand 2015-2050 HC [km^3/year]		0,89
DELTA		-30%
avg actual energy demand in CC [GWh/year]		1.260
avg actual energy demand in HC [GWh/year]		1.113
DELTA		-12%
PV of water lost in CC	M$	-202
PV of water lost in HC	M$	-140
PV of water savings with HC in 35years	M$	61
PV of energy consumed in CC	M$	199
PV of energy consumed in HC	M$	176
PV of energy expenditure if adoptiong HC for next 35years	M$	-23
WATER STRESS LEVEL(% of renewable water resource used)		16%

CARRIBEAN – DOMINICAN REPUBLIC



DOMINICAN REPUBLIC RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/m^3]	$	0,46
min WATER price Growth rate for NPV>=0		1%
min ENERGY PRICE for NPV>=0	$	0,16
min ENERGY price Growth rate for NPV>=0		6%
min 9m3/day treatment unit price	$	21.949
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		2,53
avg actual domestic demand 2015-2050 HC [km^3/year]		1,75
DELTA		-31%
avg actual energy demand in CC [GWh/year]		2.354
avg actual energy demand in HC [GWh/year]		1.963
DELTA		-17%
PV of water lost in CC	M$	-22.592
PV of water lost in HC	M$	-15.639
PV of water savings with HC in 35years	M$	6.953
PV of energy consumed in CC	M$	4.888
PV of energy consumed in HC	M$	4.079
PV of energy expenditure if adoptiong HC for next 35years	M$	-809
WATER STRESS LEVEL(% of renewable water resource used)		62%

CARRIBEAN – HAITI



HAITI RESULTS		
STATE IMPLEMENTATION	NO	
INDEPENDENT IMPLEMENTATION	NO	
min WATER PRICE for NPV>=0 [$/$m^3$]	$	0,34
min WATER price Growth rate for NPV>=0		14%
min ENERGY PRICE for NPV>=0	$	0,78
min ENERGY price Growth rate for NPV>=0		10%
min 9m3/day treatment unit price	$	-2.793
2050 OUTLOOK		
avg actual domestic demand 2015-2050 CC [km^3/year]		0,65
avg actual domestic demand 2015-2050 HC [km^3/year]		0,44
DELTA		-32%
avg actual energy demand in CC [GWh/year]		601
avg actual energy demand in HC [GWh/year]		502
DELTA		-17%
PV of water lost in CC	M$	-1.892
PV of water lost in HC	M$	-1.298
PV of water savings with HC in 35years	M$	595
PV of energy consumed in CC	M$	5.604
PV of energy consumed in HC	M$	4.678
PV of energy expenditure if adoptiong HC for next 35years	M$	-926
WATER STRESS LEVEL(% of renewable water resource used)		49%

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