IV. Simulating the Macroeconomic Impact of Future Water Scarcity

In this chapter, the macroeconomic implications of possible future water scarcity are assessed. In order to do so, the sustainability of a number of economic growth scenarios in terms of water resources are considered. The analysis is based on a comparison between potential demand for water and estimated water availability.

As was demonstrated in the previous chapter, water supply is calculated using the Global Change Assessment Model (GCAM). Three different climatic Global Circulation Models (GCMs) were used as inputs—CCSM, FIO, and GISS—to feed the complex hydrologic model. The models are described in detail in Chapter 3 Box 2. The main output of this model is an estimate of runoffs and water inflows for many regions in the world.

In this study, sustainable (renewable) water supply is defined as the total yearly runoff (where necessary integrated by water inflow) within a given region, and scenarios are considered in which this is the only available source of water. Therefore, the possible exploitation of non-renewable water resources (e.g., the so-called “fossil water”) is implicitly ruled out, whereas the adoption of unconventional water supply means (desalination, recycling, harvesting) is indirectly accounted for as improvements in water efficiency (fresh water needed per unit of economic activity).

Since demand for water is mostly an indirect demand, depending on the level of economic activity and income, a global general equilibrium model is used to conduct simulation experiments aimed at assessing changes in economic structure and trade flows, from which the demand for water is obtained.

The economic model considers 14 macro-regions:

1. North America
2. Central America
3. South America
4. Western Europe
5. Eastern Europe
6. Middle East
7. Sahel
8. Central Africa
9. Southern Africa
10. Central Asia
11. Eastern Asia
12. South Asia
13. South-East Asia
14. Australasia

In each region, in addition to the household sector, the following industries are considered:

1. Rice
2. Wheat
3. Cereals
4. Vegetables and Fruits
5. Oil Seeds
6. Sugar
7. Fibers
8. Other Crops
9. Meat
11. Processed Food
12. Textiles
13. Light Manufacturing
14. Heavy Manufacturing
15. Electricity
16. Gas
17. Water Services
18. Construction
19. Transport and Communication

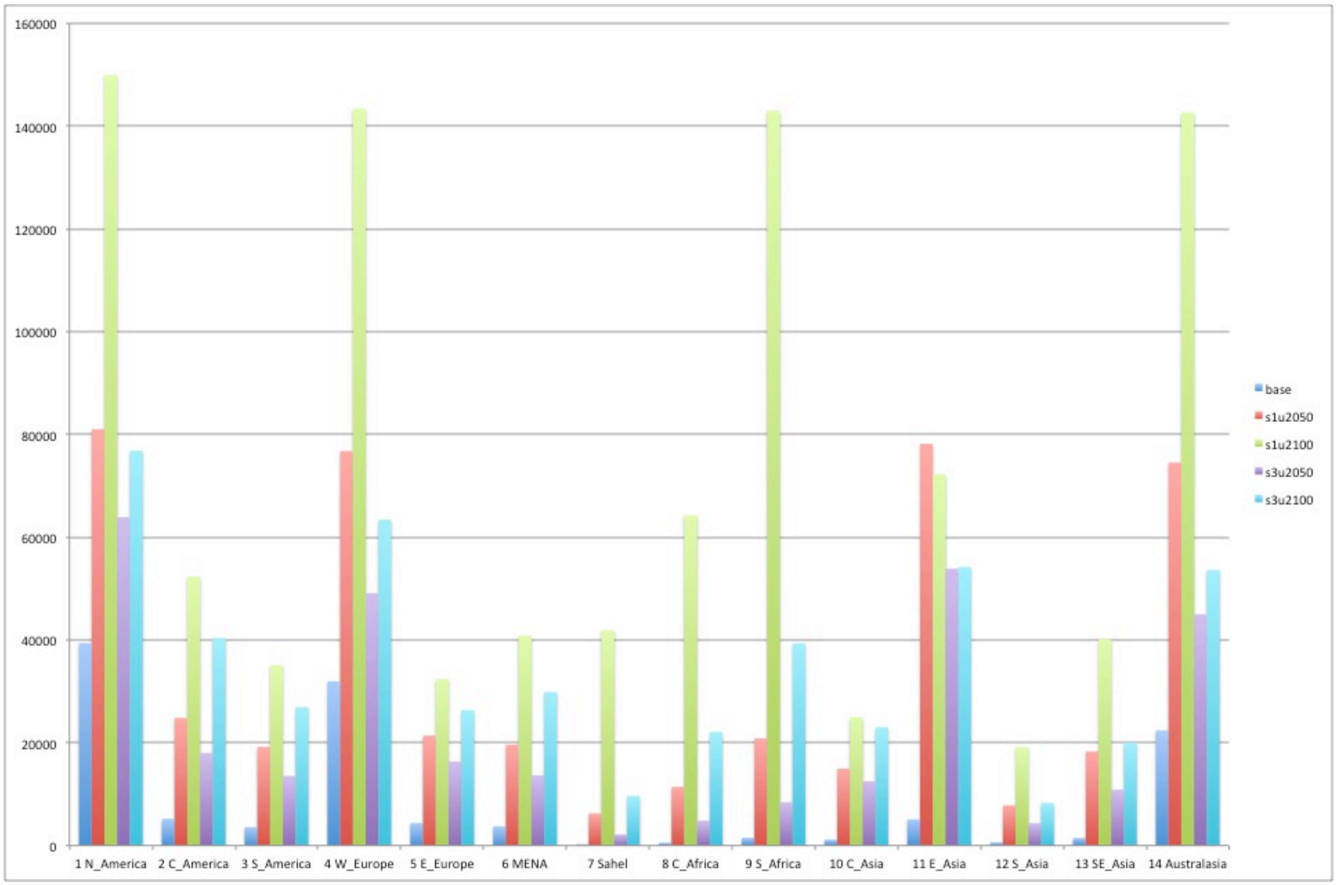
10. Extraction
20. Other Services

This exercise is conducted for two future reference years, 2050 and 2100, but policy analysis focuses on 2050 only. Two “Shared Socio-economic Pathways” (SSP) were chosen to represent two plausible, but distinct, future economic reference pathways: SSP1, termed “Sustainability”, and SSP3, termed “Regional Rivalry” (See chapter 3 box 3 for more information on SSPs). SSP1 is characterized by the following narrative: “Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land”. By contrast, SSP3 is characterized by the following narrative: “Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity”.

The analysis shows that while economic growth occurs in all regions, there is significant divergence in future income per capita between scenarios where regions cooperate to mitigate the effects of climate change on water versus scenarios where a short-term outlook is taken

The levels of income per capita (real GDP) in each of the 14 macro-regions considered are depicted in Figure 1, in the base year at which parameters of the model are calibrated (2004) and in the four scenarios (SSP1 and SSP3, 2050 and 2100). The figure helps to highlight the salient features of the four cases. SSP1/2050 (s1u2050) is characterized by dramatic income growth in East Asia, but also Australasia, where income levels get similar to those in North America and Europe. SSP1/2100 (s1u2100) exhibits very high growth rates all over the world. South Africa is the fastest growing region, whereas income per capita declines in East Asia with respect to 2050. SSP3/2050 (s3u2050) is characterized by a dual world, where developed regions (North America and Western Europe) experience a limited growth, but developing regions (most notably East Asia) grow fast. SSP3/2100 (s3u2100) shows a more balanced income distribution. North America and Western Europe slow down further after 2050 and East Asia stops growing altogether, whereas Africa and the Middle East accelerate.

Figure 1 - Income per capita in the 14 regions



By 2100, excess water demand will exist in nearly every region of the world—with the exceptions of North and South America, and Europe—implying that growth expectations for the 21st century will likely not be met if the current water regime persists

Water demand projections are based on water intensity coefficients, that is, water per unit of output. These are obtained as ratios between sectoral water usage and output in the base calibration year. In turn, sectoral consumption has been estimated by elaborating information from various sources: the WIOD project (Dietzenbacher et el., 2013), Mekonnen and Hoekstra (2011), the European research project WASSERMed (Roson and Sartori, 2015), Mielke, Diaz Anadon and Narayanamurti (2010), the U.S. Energy Information Administration (2015).

Water intensity coefficients can be used in principle, to translate the results of any simulation with the numerical economic model (for example, industrial output volumes) in terms of water demand. However, it is necessary to take into consideration that water usage per unit of production (or consumption) does vary over time. In this study, it is assumed that efficiency gains are endogenous and dependent on production growth. Specifically, it is assumed that only a fraction d of the increase in industrial production volumes in a country, from q' to q'', translates into higher water consumption w'', that is:

$$w'' = i\,(q' + d\,(q''-q')) = i\,((1-d)q'+dq'')$$

where *i* is the relevant baseline water intensity coefficient (water per unit of production), and the value of 0.5, or 50%, is assumed for the *d* parameter. Further improvements in water efficiency are posited whenever potential water demand exceeds water availability, as it will be better explained in the following section. To guard against exaggerating impacts the assumptions about technology change err towards optimism.

Table 1 shows the crude first stage results obtained for potential water demand (i.e. consumption of water resources), which simply mirrors the economic growth scenario, and is not affected by any water supply constraint.

Table 1 – Projections of sectoral water demand

Water Demand/Usage (millions of m3)

Baseline 2004

	1 N_America	2 C_America	3 S_America	4 W_Europe	5 E_Europe	6 MENA	7 Sahel	8 C_Africa	9 S_Africa	10 C_Asia	11 E_Asia	12 S_Asia	13 SE_Asia	14 Australasia
Agriculture	1320159	462666	956679	360114	838905	533776	345160	496424	276015	192685	1341460	1684088	1042806	182646
Industrial	509594	123345	172642	172151	363591	508932	6400	51398	57925	48604	301802	111472	111377	17777
Municipal	38677	25540	17794	16250	28695	29255	2788	3263	6098	5228	80122	63757	24215	1605
Total	***1868430***	***611551***	***1147115***	***548516***	***1231191***	***1071963***	***354348***	***551084***	***340038***	***246517***	***1723384***	***1859318***	***1178398***	***202028***

2050 SSP1

	1 N_America	2 C_America	3 S_America	4 W_Europe	5 E_Europe	6 MENA	7 Sahel	8 C_Africa	9 S_Africa	10 C_Asia	11 E_Asia	12 S_Asia	13 SE_Asia	14 Australasia
Agriculture	1955926	990699	2198107	468565	1828737	1280867	2737204	3083502	1051455	798891	8549132	8030985	5367159	421624
	48.16%	114.13%	129.76%	30.12%	117.99%	139.96%	693.02%	521.14%	280.94%	314.61%	537.30%	376.87%	414.68%	130.84%
Industrial	700836	288666	497493	238685	947801	1659859	86803	604495	397279	344408	2443783	751185	730931	38737
	37.53%	134.03%	188.16%	38.65%	160.68%	226.15%	1256.32%	1076.12%	585.85%	608.60%	709.73%	573.87%	556.27%	117.91%
Municipal	65660	59006	43494	25683	57253	82789	21782	24977	32240	23383	395768	285798	105966	3831
	69.77%	131.03%	144.43%	58.04%	99.53%	182.99%	681.26%	665.38%	428.69%	347.24%	393.96%	348.26%	337.60%	138.67%
Total	***2722422***	***1338371***	***2739094***	***732932***	***2833791***	***3023515***	***2845790***	***3712974***	***1480974***	***1166681***	***11388684***	***9067968***	***6204056***	***464193***
	45.71%	118.85%	138.78%	33.62%	130.17%	182.05%	703.11%	573.76%	335.53%	373.27%	560.83%	387.70%	426.48%	129.77%
Var. GDP	142.88%	399.98%	456.41%	157.58%	379.45%	484.67%	2160.78%	2085.80%	1341.60%	1204.73%	1426.42%	1175.79%	1151.44%	300.67%

2100 SSP1

	1 N_America	2 C_America	3 S_America	4 W_Europe	5 E_Europe	6 MENA	7 Sahel	8 C_Africa	9 S_Africa	10 C_Asia	11 E_Asia	12 S_Asia	13 SE_Asia	14 Australasia
Agriculture	2576822	1347124	2941365	606135	2097823	1779373	13481650	10712068	3529485	1014491	6732773	14165877	9119300	620023
	95.19%	191.17%	207.46%	68.32%	150.07%	233.36%	3805.91%	2057.85%	1178.73%	426.50%	401.90%	741.16%	774.50%	239.47%
Industrial	970751	426260	730056	329211	1174845	2642777	602869	3161105	2038592	532039	2017938	1685731	1459962	56300
	90.49%	245.58%	322.87%	91.23%	223.12%	419.28%	9319.96%	6050.29%	3419.34%	994.65%	568.63%	1412.24%	1210.83%	216.71%
Municipal	85075	80685	54438	31884	63922	111587	103995	100349	149064	30498	301933	521091	174747	5049
	119.97%	215.91%	205.94%	96.21%	122.77%	281.42%	3629.95%	2975.05%	2344.44%	483.34%	276.84%	717.31%	621.64%	214.52%
Total	***3632648***	***1854068***	***3725858***	***967231***	***3336589***	***4533736***	***14188515***	***13973522***	***5717141***	***1577028***	***9052644***	***16372699***	***10754008***	***681373***
	94.42%	203.17%	224.80%	76.34%	171.01%	322.94%	3904.12%	2435.64%	1581.32%	539.72%	425.28%	780.58%	812.60%	237.27%
Var. GDP	334.80%	897.57%	869.69%	360.11%	603.08%	1033.52%	14511.25%	11754.79%	9392.58%	2030.24%	1268.25%	2954.64%	2585.61%	624.45%

2050 SSP3

	1 N_America	2 C_America	3 S_America	4 W_Europe	5 E_Europe	6 MENA	7 Sahel	8 C_Africa	9 S_Africa	10 C_Asia	11 E_Asia	12 S_Asia	13 SE_Asia	14 Australasia
Agriculture	1675704	950289	1951556	366545	1587041	1169091	1472979	2038368	720910	749425	6372489	5644760	3763355	287768
	26.93%	105.39%	103.99%	1.79%	89.18%	119.02%	326.75%	310.61%	161.19%	288.94%	375.04%	235.18%	260.89%	57.56%
Industrial	594637	263415	416307	178118	785532	1351739	34718	298378	197637	301477	1732473	467757	473415	25737
	16.69%	113.56%	141.14%	3.47%	116.05%	165.60%	442.47%	480.53%	241.19%	520.28%	474.04%	319.62%	325.06%	44.78%
Municipal	50095	60480	41939	17899	48770	76964	13269	16463	21253	21887	292409	202855	77095	2620
	29.52%	136.80%	135.69%	10.15%	69.96%	163.08%	375.93%	404.50%	248.51%	318.62%	264.96%	218.17%	218.38%	63.22%
Total	***2320436***	***1274184***	***2409802***	***562563***	***2421343***	***2597794***	***1520967***	***2353210***	***939799***	***1072788***	***8397372***	***6315372***	***4313866***	***316126***
	24.19%	108.35%	110.08%	2.56%	96.67%	142.34%	329.23%	327.01%	176.38%	335.18%	387.26%	239.66%	266.08%	56.48%
Var. GDP	73.44%	308.59%	331.47%	49.09%	267.02%	347.84%	830.60%	955.50%	568.12%	1020.51%	953.98%	644.31%	669.92%	133.21%

2100 SSP3

	1 N_America	2 C_America	3 S_America	4 W_Europe	5 E_Europe	6 MENA	7 Sahel	8 C_Africa	9 S_Africa	10 C_Asia	11 E_Asia	12 S_Asia	13 SE_Asia	14 Australasia
Agriculture	1579208	1583227	3064792	330349	2087559	1946611	4700938	6177767	1896506	1129303	5884684	8798887	5769197	281219
	19.62%	242.20%	220.36%	-8.27%	148.84%	264.69%	1261.96%	1144.46%	587.10%	486.09%	338.68%	422.47%	453.24%	53.97%
Industrial	541553	444730	707642	164499	1088114	2402876	136372	1186300	641149	522309	1615993	822991	789906	22389
	6.27%	260.56%	309.89%	-4.45%	199.27%	372.14%	2030.84%	2208.08%	1006.85%	974.63%	435.45%	638.29%	609.22%	25.94%
Municipal	43144	96541	62444	14809	62063	120288	35161	46656	56783	32374	250046	294545	108890	2263
	11.55%	278.00%	250.93%	-8.87%	116.29%	311.17%	1161.10%	1329.70%	831.16%	519.22%	212.08%	361.98%	349.68%	40.94%
Total	***2163905***	***2124498***	***3834878***	***509657***	***3237736***	***4469776***	***4872471***	***7410723***	***2594439***	***1683986***	***7750723***	***9916423***	***6667992***	***305870***
	15.81%	247.40%	234.31%	-7.08%	162.98%	316.97%	1275.05%	1244.75%	662.98%	583.11%	349.74%	433.34%	465.85%	51.40%
Var. GDP	82.57%	793.82%	748.21%	63.51%	494.36%	847.50%	3632.63%	4317.64%	2726.50%	1944.13%	937.64%	1293.47%	1292.11%	146.53%

To estimate the regional “sustainable water supply”, results from the GCAM hydrologic model have been used. Water supply in each macro-region is expressed as the sum of yearly runoffs of all countries belonging to the region, averaged for three GCMs climate scenarios. Results are summarized in Table 2.

Table 2 – Water Supply Data (billions of m^3)

AVERAGE TOTAL RUNOFF	2005	2050	2100		ST.DEV.	2005	2050	2100
1 N_America	5455	5252	5304		1 N_America	210	159	206
2 C_America	2022	1971	1544		2 C_America	111	127	354
3 S_America	8101	8186	8519		3 S_America	472	325	1199
4 W_Europe	1434	1456	1463		4 W_Europe	19	56	18
5 E_Europe	5797	5088	5059		5 E_Europe	39	123	190
6 Middle East	499	393	362		6 Middle East	36	36	28
7 Sahel	1129	947	953		7 Sahel	71	57	79
8 C_Africa	2642	2336	2544		8 C_Africa	170	69	40
9 S_Africa	1275	1396	1345		9 S_Africa	101	210	205
10 C_Asia	532	437	414		10 C_Asia	76	31	38
11 E_Asia	2539	2320	2282		11 E_Asia	83	115	34
12 S_Asia	1698	1711	1792		12 S_Asia	240	86	188
13 SE_Asia	4822	5367	5373		13 SE_Asia	345	225	423
14 Australasia	1027	1067	1085		14 Australasia	198	114	20

Observe that regional water availability is not expected to change dramatically during the 21st century, whereas (potential) water demand would necessarily follow the underlying assumptions of baseline GDP and population. The emerging regional gap between potential demand and actual “sustainable” water supply is highlighted in Tables 3 (SSP1) and 4 (SSP3).

Table 3 – Water Demand Projections SSP1 and Percentage Excess Demand

SSP1	2005	2050	2100		GAP %	2005	2050	2100
1 N_America	1868	2722	3633		1 N_America	0.0	0.0	0.0
2 C_America	612	1338	1854		2 C_America	0.0	0.0	-16.7
3 S_America	1147	2739	3726		3 S_America	0.0	0.0	0.0
4 W_Europe	549	733	967		4 W_Europe	0.0	0.0	0.0
5 E_Europe	1231	2834	3337		5 E_Europe	0.0	0.0	0.0
6 Middle East	1072	3024	4534		6 Middle East	-53.5	-87.0	-92.0
7 Sahel	354	2846	14189		7 Sahel	0.0	-66.7	-93.3
8 C_Africa	551	3713	13974		8 C_Africa	0.0	-37.1	-81.8
9 S_Africa	340	1481	5717		9 S_Africa	0.0	-5.8	-76.5

10 C_Asia	247	1167	1577		10 C_Asia	0.0	-62.5	-73.8
11 E_Asia	1723	11389	9053		11 E_Asia	0.0	-79.6	-74.8
12 S_Asia	1859	9068	16373		12 S_Asia	-8.7	-81.1	-89.1
13 SE_Asia	1178	6204	10754		13 SE_Asia	0.0	-13.5	-50.0
14 Australasia	202	464	681		14 Australasia	0.0	0.0	0.0

Table 4 – Water Demand Projections SSP3 and Percentage Excess Demand

SSP3	2005	2050	2100		GAP %	2005	2050	2100
1 N_America	1868	2320	2164		1 N_America	0.0	0.0	0.0
2 C_America	612	1274	2124		2 C_America	0.0	0.0	-27.3
3 S_America	1147	2410	3835		3 S_America	0.0	0.0	0.0
4 W_Europe	549	563	510		4 W_Europe	0.0	0.0	0.0
5 E_Europe	1231	2421	3238		5 E_Europe	0.0	0.0	0.0
6 Middle East	1072	2598	4470		6 Middle East	-53.5	-84.9	-91.9
7 Sahel	354	1521	4872		7 Sahel	0.0	-37.7	-80.4
8 C_Africa	551	2353	7411		8 C_Africa	0.0	-0.8	-65.7
9 S_Africa	340	940	2594		9 S_Africa	0.0	0.0	-48.2
10 C_Asia	247	1073	1684		10 C_Asia	0.0	-59.2	-75.4
11 E_Asia	1723	8397	7751		11 E_Asia	0.0	-72.4	-70.6
12 S_Asia	1859	6315	9916		12 S_Asia	-8.7	-72.9	-81.9
13 SE_Asia	1178	4314	6668		13 SE_Asia	0.0	0.0	-19.4
14 Australasia	202	316	306		14 Australasia	0.0	0.0	0.0

Water consumption in the Middle East (and, to a lesser extent, in South Asia [India and neighboring countries]) already exceeds “sustainable” water consumption in these scenarios. This suggests that in these regions non-renewable water resources would need to be exploited that might include unsustainable abstraction of groundwater.

However, in 2050 and 2100 water resources become insufficient in several other regions, all located in Africa and Asia. This implies that for those regions, the strong economic development scenarios are incompatible with the estimated availability of water resources. Equivalently, the analysis highlights that water (or water scarcity) has been neglected in the definition of the Shared Socio-Economic Pathways suggesting a potential inconsistency.

Under business-as-usual scenarios, future global water supply is insufficient to keep up with future global water demand. Nevertheless, smart policies coupled with increases in water use efficiency can prevent production shortfalls and avoid reductions of growth in most regions

How can the emerging water demand gap be accommodated in the water-constrained regions? Three complementary ways are envisaged:

- If water is a non-substitutable production factor, production should fall in all water-consuming industries by the same percentage of the excess demand gap. From Tables 3 and 4 one can see that this gap is generally large, which would imply dramatic and unrealistic drops in production levels. In any case, at least some part of the demand gap (in this exercise 1/4 is assumed) translates into production cuts or, in economics jargon, into reductions of multi-factor productivity. But in practice there is (albeit limited) factor substitutability, so this represents the worst case that is unlikely to prevail.

- As water becomes a scarcer resource, its explicit market price or its shadow cost would rise, reducing the relative competitiveness of water intensive activities. Within each industry in the large macro-regions, activities would then be reallocated in time and space (by specific policies or by market forces), and more efficient water techniques would be adopted. These mechanisms end up reducing the industrial water intensity coefficients, by increasing overall water efficiency. It is assumed here that this effect can cover 3/4 of the demand gap (other parameter values have also been used to test robustness, but for brevity are not discussed here).

- In addition to efficiency-improving reallocations *within* industries, water would be reallocated *between* industries. This either requires establishing water markets or specific policies at the national or regional level. The inverse of the water intensity coefficient is the value of production per unit of water, that is, the water industrial productivity. Recognizing that perfect reallocations are improbable and unrealistic, policy scenarios are explored, where the cut in water consumption levels is not applied uniformly across all industries, but smaller reductions are applied where water is relatively more valuable (and vice versa). Three cases are discussed here: (1) no inter-industrial water reallocation [NO-WR], (2) mild [MILD] and (3) strong [STRONG] water reallocation.

Table 5 (SSP1) and Table 6 (SSP3) present estimates of variations in real GDP, for all macro-regions and for the world as a whole, under the three policy scenarios NO-WR, MILD and STRONG, relative to the 2050 baseline of unconstrained economic growth.

Table 5 – Percentage Variation in Real GDP (SSP1, 2050)

	NO-WR	MILD	STRONG
1 N_America	-0.02	-0.02	0
2 C_America	0.07	0.08	0.14
3 S_America	-0.04	-0.02	0.01
4 W_Europe	-0.02	-0.02	-0.01
5 E_Europe	0.1	0.08	0.05
6 Middle East	-14	-8.93	-6.02
7 Sahel	-11.7	-10.67	-0.82
8 C_Africa	-7.08	-5.52	-3.09
9 S_Africa	-0.75	-0.42	0.17
10 C_Asia	-10.72	-7.47	11.5
11 E_Asia	-7.05	-3.75	3.32
12 S_Asia	-10.1	-7	1.44
13 SE_Asia	-1.98	-1.12	1.46
14 Australasia	-0.05	-0.02	0.04
WORLD	-0.37	-0.21	0.08

Without reallocation of water resources among sectors, water scarcity imposes a reduction to the world real GDP of -0.37% in the SSP1 and -0.49% in the SSP3. However there are large disparities across regions, with a large drop in income for some regions, but small gains in some other regions (e.g., Central America) due to improved terms of trade and relative competitiveness. In monetary terms, the global welfare impact of water scarcity (equivalent variation) amounts to US$762 billion for SSP1 and US$712 billion of for SSP3, with most of the burden concentrated in East Asia (around 62% of the total) and the Middle East (23%).

A complete different picture emerges when some redistribution of water resources across sectors is allowed. Industrial water reallocations are guided by an equation where an elasticity parameter (with values set at 0, 0.1, 0.25 for the three policy scenarios) determines the sensitivity to the relative water productivity. With a limited reallocation of water (MILD) the reduction of global GDP is reduced by 42% in both scenarios, whereas regional reductions range from -22% to -67%.

Table 6 – Percentage Variation in Real GDP (SSP3, 2050)

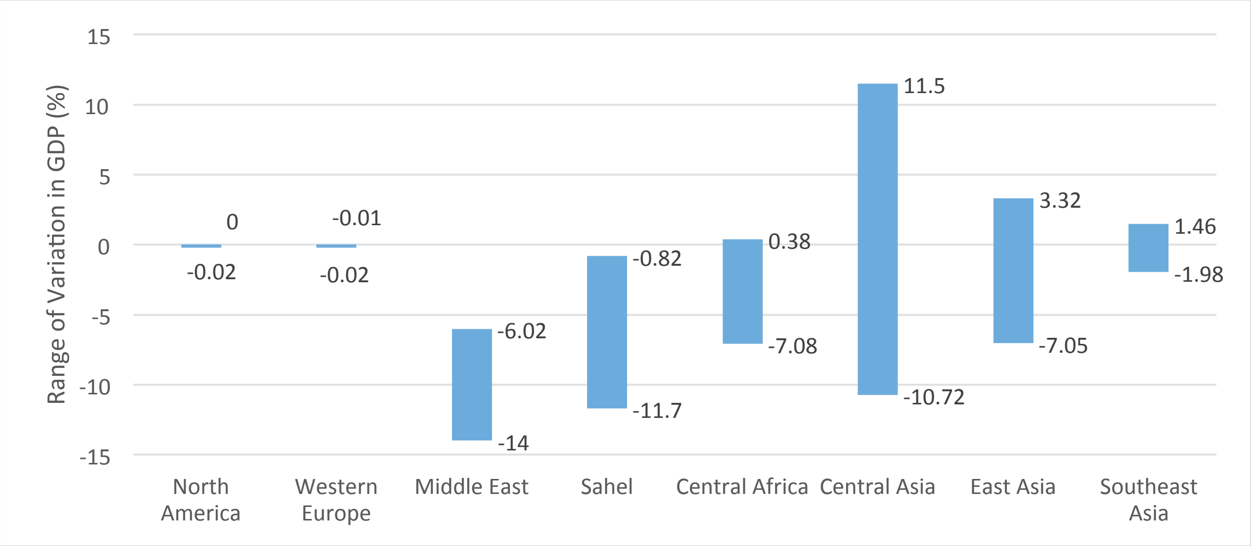
	NO-WR	MILD	STRONG
1 N_America	-0.02	-0.01	0
2 C_America	0.08	0.09	0.15
3 S_America	-0.02	-0.01	0.02
4 W_Europe	-0.01	-0.01	-0.01
5 E_Europe	0.07	0.05	0.03
6 Middle East	-13.96	-8.95	-6.21

7 Sahel	-7.21	-6.7	-0.98
8 C_Africa	0.18	0.21	0.38
9 S_Africa	-0.07	-0.01	0.09
10 C_Asia	-10.3	-7.19	10.98
11 E_Asia	-6.44	-3.43	2.95
12 S_Asia	-9.33	-6.51	1.03
13 SE_Asia	-0.06	-0.04	0.03
14 Australasia	-0.03	-0.01	0.04
WORLD	-0.49	-0.28	0.09

Furthermore, when the water reallocation is more pronounced (STRONG), it turns out that global real GDP increases. The same applies to regional GDP in many water-constrained regions, although GDP losses are still observed where the water demand gap is very large (e.g., in the Middle East). This is because, with a sufficiently high value for the elasticity parameter, some industries (where water is more valuable) get cuts in water endowments that are more than compensated by improvements in water efficiency, ultimately increasing total productivity. In monetary terms, the welfare equivalent cost of water scarcity becomes a *gain*, of US$214 billion for SSP1 and $US165 billion for SSP3.

This “reversal effect” shown most clearly in Figure 2, which displays the range of the effect of water scarcity on global growth, for all four scenarios. The lower bounds in this figure come from the SSP1, no water reallocation [NO-WR] scenario for all regions, and the upper bound is from SSP1, strong water reallocation for all regions except for Central Africa, where SSP3, strong water reallocation leads to better growth. However, regardless of which SSP is chosen, the difference between the two policy scenarios can be dramatic in some regions, most notably in Central Asia (getting a net increase of GDP of around +22.2% from moving from no water reallocation to strong water reallocation). This is due to a combination of factors. First, a region may be characterized by large differences in the industrial water productivity, so that when the allocation scheme becomes more sensitive to productivity differentials, significant variations in water endowments and, consequently, on the overall factor productivity will follow (see Table 7 below). Second, the net aggregate effect also depends on how large the “winning industries” are in the regional economic structure. For example, in Central Asia when Extraction, Light Manufacturing, Transport, and Communication are allowed to use more water (despite reductions in total regional water consumption), this vastly improves overallindustrial productivity. Furthermore, these sectors are already relatively large in the structure of the Central Asian economy, making their impact on regional GDP substantial.

Figure 2: Range of Variation in 2050 GDP across SSP1 and SSP3, and 3 different policy levels



Simulations show that with strong water reallocation, water scarcity will lead to a large reduction in agricultural production in water scarce regions, where production will shift to the less intensive manufacturing sector

Simulations with the Computable General Equilibrium (CGE) model entail shocking industrial productivity parameters, in a way that is consistent with the underlying hypotheses of water availability and water intensity in each sector. The model computes a counterfactual equilibrium for the world economy and provides a rich set of output in terms of: production and consumption volumes, investments, relative prices, trade flows, and many other economic variables. See Box 1 for a more thorough description of the CGE model.

Box 1: A brief description of the GTAP model

The Global Trade Analysis Project (GTAP) is an international network, which builds, updates and distributes a comprehensive and detailed data base of trade transactions among different industries and regions in the world, framed as a Social Accounting Matrix (SAM). The SAM is typically used to calibrate parameters for a Computable General Equilibrium (CGE) model, and the GTAP data base is accompanied by a relatively standard CGE model and its software. The model structure is quite complex and it is fully described in Hertel and Tsigas (1997). For brevity, summaries of the meaning of the main equations of the model are presented, and a graphical representation of income flows in the model is shown in Figure A1 (from Brockmeier, 2001).

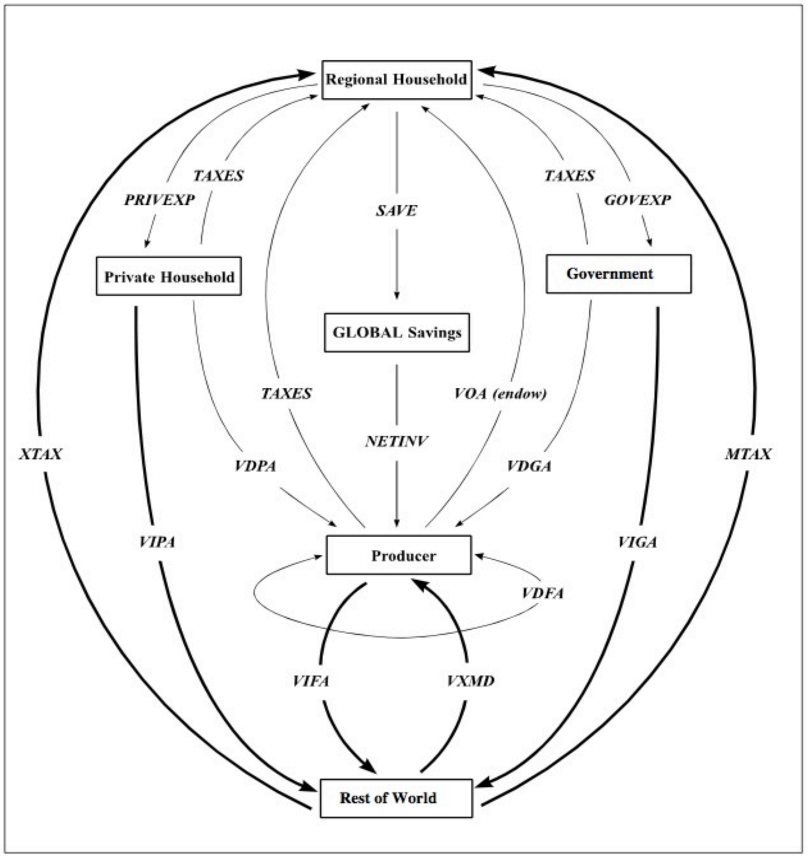


Figure A1 – Income flows in the GTAP Model

Equation and identities in the model include the following conditions:

- production of industry *i* in region *r* equals intermediate domestic consumption, final demand (private consumption, public consumption, demand for investment goods) and exports to all other regions;
- endowments of primary factors (e.g., labor, capital) matches demand from domestic industries;
- unit prices for goods and services equals average production costs, including taxes;
- representative firms in each regional industry allocate factors on the basis of cost minimization;
- available national income equals returns on primary factors owned by domestic agents;
- national income is allocated to private consumption, public consumption and savings;
- savings are virtually pooled by a world bank and redistributed as regional investments, on the basis of expected future returns on capital;
- the structure of private consumption is set on the basis of utility maximization under budget constraint;
- intermediate and final demand is split according to the source of production: first between domestic production and imports, subsequently the imports among the various trading partners. Allocation is based on relative market prices, including transportation, distribution, and tax margins. Goods in the same industry but produced in different places are regarded as imperfect substitutes;
- there is perfect domestic mobility for labour and capital (single regional price), but no international mobility;

- there is imperfect domestic mobility for land (industry-specific price), but no international mobility. Land allocation is driven by relative returns.

From a mathematical point of view, the model is a very large non-linear system of equations. Structural parameters are set so that the model replicates observational data in a base year. Simulations entail changing some exogenous variables or parameters, bringing about the determination of a counterfactual equilibrium. The partition between endogenous and exogenous variables, as well as the regional and industrial disaggregation level, is not fixed but depends on the scope of the simulation exercise.

It is not possible to illustrate in detail all the findings of the different simulation exercises in this report. Rather, to show how the economic structure is typically affected, some results for the SSP1/2050 scenario with STRONG water inter-industrial reallocation are described below.

Table 7 – Changes in multi-factor productivity (SSP1, 2050, STRONG)

	N_America	C_America	S_America	W Europe	E Europe	M. East	Sahel	C_Africa	S_Africa	C_Asia	E_Asia	S_Asia	SE_Asia	Austr
Rice	0.00%	0.00%	0.00%	0.00%	0.00%	-42.30%	-15.92%	-17.10%	-4.01%	-42.47%	-37.12%	-40.21%	-6.00%	0.00%
Wheat	0.00%	0.00%	0.00%	0.00%	0.00%	-40.47%	-20.23%	-0.98%	-1.32%	-25.34%	-44.20%	-28.34%	-4.19%	0.00%
Cereals	0.00%	0.00%	0.00%	0.00%	0.00%	-41.89%	-31.20%	-10.70%	-2.72%	-18.23%	-48.74%	-34.41%	-3.08%	0.00%
VegFruit	0.00%	0.00%	0.00%	0.00%	0.00%	-28.74%	-4.92%	-9.96%	-1.95%	2.57%	-15.86%	-14.37%	-4.43%	0.00%
Oilseeds	0.00%	0.00%	0.00%	0.00%	0.00%	-37.66%	-24.66%	-6.87%	-2.38%	-84.58%	-31.88%	-21.49%	1.43%	0.00%
Sugar	0.00%	0.00%	0.00%	0.00%	0.00%	-33.51%	-22.90%	-3.78%	-1.78%	-10.71%	-35.44%	-20.61%	-4.14%	0.00%
Other Crops	0.00%	0.00%	0.00%	0.00%	0.00%	-21.01%	-7.76%	-9.88%	-1.10%	11.42%	-0.57%	6.91%	-1.52%	0.00%
Oth Agr.	0.00%	0.00%	0.00%	0.00%	0.00%	-21.41%	-14.66%	-11.35%	-0.78%	6.53%	-8.26%	-9.25%	-2.15%	0.00%
Extr	0.00%	0.00%	0.00%	0.00%	0.00%	-15.64%	15.74%	0.71%	-0.21%	17.46%	4.72%	9.86%	2.16%	0.00%
P.Food	0.00%	0.00%	0.00%	0.00%	0.00%	6.81%	29.57%	7.12%	1.11%	30.82%	18.57%	22.97%	4.61%	0.00%
Textiles	0.00%	0.00%	0.00%	0.00%	0.00%	7.45%	28.02%	6.25%	0.98%	29.37%	18.68%	24.65%	4.43%	0.00%
Light Man	0.00%	0.00%	0.00%	0.00%	0.00%	7.59%	30.63%	7.72%	1.21%	31.82%	18.27%	19.89%	4.83%	0.00%
Heavy Man	0.00%	0.00%	0.00%	0.00%	0.00%	4.60%	28.63%	6.60%	1.03%	29.94%	16.42%	19.13%	4.35%	0.00%
Utilities	0.00%	0.00%	0.00%	0.00%	0.00%	-12.96%	15.68%	-0.66%	-0.09%	17.78%	3.10%	8.79%	1.43%	0.00%

Table 7 shows how the multi-factor productivity changes in the water consuming industries of the various regions. Industry in non-water constrained regions are unaffected. In the other cases, there can be both increases and decreases in productivity. This is because water is reduced, by different amounts (depending on relative water returns), but all industries improve in terms of water efficiency. When improvements in water efficiency more than compensate for the cuts in water availability, industrial productivity rises. It can be easily noticed that this generally implies a shift in the economic structure away from agricultural production, to the benefit of manufacturing and food processing.

By shifting production to less water intensive sectors, and importing more water intensive goods, water scarce regions can adapt to a changing water environment

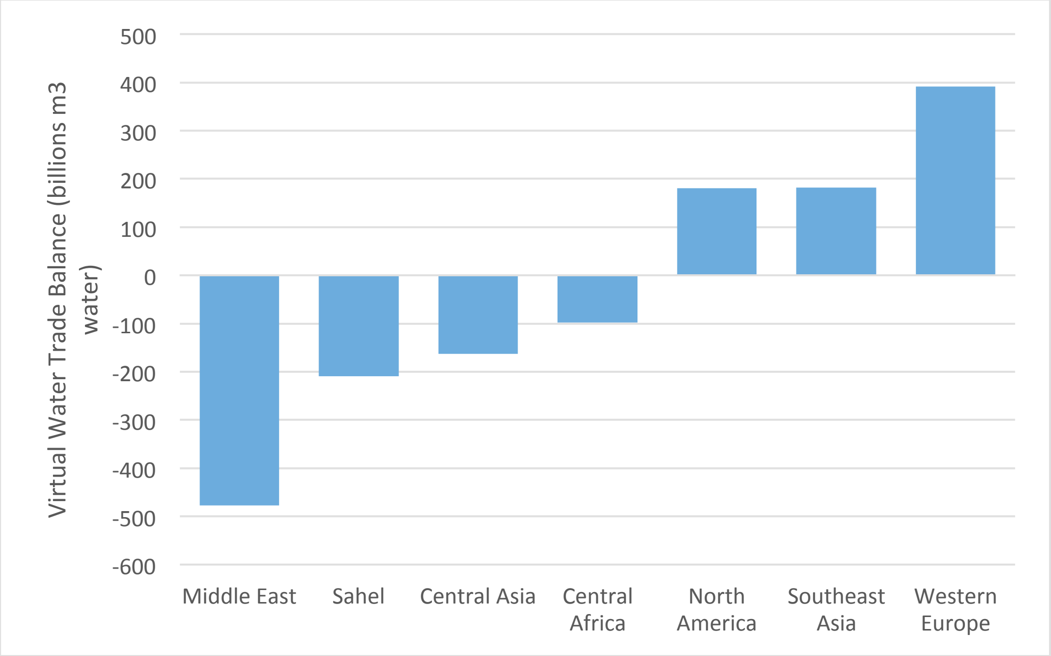
Another interesting way to look at the changes in the economic structure is by analyzing the variations in virtual water trade flows. Virtual water trade refers to the implicit content of water in import and export flows. The water intensity coefficients can be employed to estimate the amount of water that was used to produce goods that have been subsequently transferred abroad, which can be interpreted as a virtual export of water. Table 8 presents the changes in virtual water flows (in billions m^3) among the 14 macro-regions, again for the scenario SSP1/2050/STRONG.

The reduction in agricultural production and other water consuming activities in water constrained regions implies a substitution of domestic water-consuming goods with imports, that is, an increase in virtual water imports. The difference between row and column totals gives the changes in the "virtual water trade balance" for each region. These differences are summed and presented in Figure 3. Here it is found that, as a consequence of market mechanisms affecting regional economic structures, the most water constrained region, the Middle East, increases its net imports of virtual water by about 478 billion m^3. Other water-constrained regions also increase net importers of virtual water: Sahel (210 billion m^3) Central Asia (164), Central Africa (98). The global virtual water trade balance must equal zero, implying that non-water constrained regions will expand their exports of virtual water.

Table 8 – Changes in virtual water trade flows (SSP1, 2050, STRONG)

from\to	N_Am	C_Am	S_Am	W_Eu	E_Eu	M. East	Sahel	C_Afr	S_Afr	C_Asia	E_Asia	S_Asia	SE_Asia	Austr	Tot.
N_Am	0	-2280	-288	-581	1	2867	-63	-66	-60	2	4271	83	82	12	**3982**
C_Am	68	0	6	231	23	248	1	8	1	0	430	-21	7	4	**1005**
S_Am	35	19	0	626	227	4404	32	161	-29	19	2014	37	140	14	**7699**
W_Eu	-42	-4	-2	0	-17	559	12	32	-12	0	-3	-77	-11	0	**435**
E_Eu	91	-27	-2	-2035	0	9263	-107	10	-29	13	487	90	206	6	**7966**
M. East	-29405	-1157	-3579	-74484	-6055	0	-576	-2170	-12783	-416	-373879	-50614	-78477	-2021	**-635615**
Sahel	-8976	-1783	-1712	-43556	-2211	-26877	0	-25440	-3719	-24	-78762	-8492	-14663	-456	**-216669**
C_Afr	-24641	-1094	-5374	-68558	-3746	-4582	-2038	0	-4930	-243	-62724	-24279	-6567	-396	**-209170**
S_Afr	-417	-76	-80	-3971	-220	-46	-52	-385	0	-19	-4871	-130	-653	-30	**-10947**
C_Asia	-2660	-2724	-586	-22522	-86955	-21663	-21	-60	-283	0	-25800	-1858	-646	-100	**-165879**
E_Asia	-45054	-6324	-3242	-52678	-9300	-10402	-1049	-2907	-3871	-827	0	-3219	-46907	-3327	**-189104**
S_Asia	-53602	-8264	-2393	-99100	-9193	-115817	-1990	-75700	-23714	-736	-108192	0	-128967	-2882	**-630550**
SE_Asia	-11803	-1504	-965	-24063	-1847	2591	-1035	-4737	-2324	-32	-43591	-2306	0	-2691	**-94306**
Austr	13	-21	-12	-255	0	1515	-33	-54	-213	0	27	121	-49	0	**1040**
Tot.	**-176393**	**-25239**	**-18227**	**-390945**	**-119293**	**-157940**	**-6919**	**-111306**	**-51966**	**-2261**	**-690591**	**-90665**	**-276505**	**-11866**	

Figure 3: Virtual Water Trade Balance



Conclusions

In this chapter, findings of some numerical simulation exercises aimed at assessing the macroeconomic consequences of a possible future scarcity of water have been presented. It is important to emphasize that models are not designed to forecast the future. As with all modeling exercises, the analysis is based upon a litany of assumptions and cannot be interpreted as predictions of future changes in GDP. Instead the exercise serves to improve understanding of the magnitude and direction of changes and how alternative policies can either accentuate or mitigate the adverse impacts.

The results demonstrate that water remains a significant, growth and development obstacle in the context of a changing climate. It also forcefully illustrates that prudent management of water resources is likely sufficient to neutralize some of the undesirable impacts.

Along the way several assumptions have been introduced, which are all more or less questionable. Nevertheless, the main results are robust to alternative conjectures, and three main messages emerge from the analysis.

First, scenarios of economic development that have been recently proposed to support the scientific analyses of climate change have ignored water availability. The underlying assumptions of sustained economic growth, especially for developing countries, would imply an excessive consumption of water, even when substantial improvements in water efficiency are envisaged.

Second, and related to the previous point, the emerging water scarcity will mainly affect developing countries in Africa and Asia, hampering their prospects of economic growth. This means that water scarcity will increase economic inequality around the world.

Third, an intelligent reallocation of scarce water resources towards sectors where the economic return per unit of water is higher can be a very effective policy response to the emerging water scarcity and its consequences. The analysis reveals that with a STRONG reallocation of water (implying aggressive policies in many countries), would it be possible to mitigate the macroeconomic impacts (e.g., measured by GDP) due to water resources scarcity. Of course, the model says nothing about how this reallocation could be implemented in practice. The introduction of water markets (i.e. efficient water pricing) or a more market-oriented planning of water infrastructure could be part of the solution. These are issues that have been widely discussed in the water management literature and are beyond the scope of this modeling exercise.

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