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21st Century water withdrawal decoupling: A pathway to a more water-wise world?☆

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ABSTRACT

Human demand for adequate water resources and supplies has been and will continue to be a fundamental issue in the 21st century due to rapid population growth, growing economies and globalization, and increasing water pollution, among others. Water withdrawals in regions which are already encountering scarcity will impose intensifying pressure on water resources locally and globally, threatening the achievement of long-term sustainable development targets. Decoupling has increasingly been recognized and incorporated in policy making as a way to reconcile limitless economic growth with environmental pressures. Filling evident literature gaps, the current state and projected future decoupling factors of water withdrawals in relation to GDP are assessed through decoupling and regression analyzes for 155 countries and 12 potential socioeconomic development pathway scenarios. Findings suggest that average levels of water withdrawal decoupling are moderate in 2025 but will increase throughout the century in all countries. By 2075, average water withdrawal decoupling becomes common and widespread, with high decoupling factors across the world. Yet, some countries and regions will continue to lag behind in this development. GDP growth is the most significant driver of water withdrawals. Climate and regional differences among countries are major influential factors on decoupling outcomes, more so than current country-level income group classification. Altogether, these results are of high significance to water resource managers and policy actors, offering a chance to act proactively to change the course on global water resource and country-specific development. In this way, decoupling provides a pathway to a more water-wise world.

1. Introduction

Meeting the continuously increasing and unsustainable demand for water across the planet has been and will continue to be one of the major challenges facing humanity in the 21st century. Jaeger et al. [1], Jarvis [2], Garrick and Hahn [3], Jaeger et al. [1], Jarvis [2], and Garrick and Hahn [3] define water scarcity as the marginal value of a unit of water, highlighting its high variability across space and time while distinguishing it from water deficit. Although water scarcity has long been an issue [4,5], discussions on global water resources only became a central topic in international development and environmental policy with meetings like the First World Water Forum in 1997 and the World Summit on Sustainable Development in 2002 [6]. However, it was not until 2010 that the United Nations General Assembly (UNGA) explicitly recognized the human right to water, calling it indispensable

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for the realization of all human rights and a dignified life [7,8]. As a result, access to safe and sufficient water emerged at the core of the 2030 Agenda for Sustainable Development [9]. Therein, it was acknowledged that apart from being a basic human necessity, water availability as well as management plays a key role in sustainable development and the overall achievement of the Sustainable Development Goals (SDGs) due to its strong linkages with the other aspired and ambitious targets [9]. Thus, the successful implementation of the 2030 SDG Agenda hinges upon meeting SDG6, achieving universal and equitable access to safe and affordable water by 2030 [10].

Despite the importance of water and the inter-linkages to every desirable societal goal being understood, the trends in water withdrawal and issues surrounding the topic of water are pointing the wrong way. Following an in-depth review of SDG6, the High-level Political Forum concluded that "the world is not on track to achieve SDG6 by 2030" [11,12]. This statement comes as no surprise when looking at the historical development of water withdrawal, which represents the total volume of water being removed from a water source, a portion of which may be returned to said source and reused. According to Wada et al. [13], during the last 100 years, global water withdrawals increased six-fold, with no downward curve in sight. Yao et al. [14] cite that this rise in water withdrawal came at twice the rate of population growth. Naturally, water shortages became more of a problem over the past century [4].

Today, the distribution of freshwater is highly uneven [15], with many regions being considered water scarce. According to estimates, water shortages or water stress are causing physical water scarcity for approximately one third of the planet's population [4,15–17]. In fact, it is predicted that most countries will experience water shortage and scarcity problems by the year 2025 [18–20]. Several factors are at the root of these forecasts. Climate change has many detrimental effects on water availability [21] including the loss of significant freshwater reservoirs [20]; rising population and living standards as well as increased food production are putting growing pressures on water resources [22–24]; concerns about water pollution from agriculture and industry are mounting [25]; and rapid urbanization only amplifies water demand and per capita shortages [26,27]. Counteracting factors to these negative impacts are the saturation of water need, improved technologies, or increased rainfall in many areas. Yet, the overall downward trend will continue. In summary, the maximum global potential for the withdrawal of freshwater is approaching fast, as the challenge of sustainable water use becomes continually more difficult [5,22,28]. In this regard, with water scarcity increasing and the craving for adequate water supplies inching closer to total water availability in various regions, each water drop becomes increasingly valuable [13,29,30]. Hence, the need for sustainable, efficient, and equitable water management is more urgent than ever.

To avert the impending crisis, scholars have argued for shifting the focus away economic growth [31–38]. On this subject, increasing emphasis on the notion of sustainable development, suggesting that economic growth can be reconciled with planetary boundaries [39], gave rise to the decoupling concept.

In short, "the term decoupling refers to breaking the link between environmental bads and economic goods" [40, p.4]. Decoupling theorizes that the demand for resources like water can be curbed while economic and population growth continues [41]. If GDP grows, absolute decoupling happens when the growth rate of the environmental indicator, such as water withdrawal, stabilizes or decreases [40]. Alternatively, relative decoupling suggests that said rate is less than GDP growth [40]. Ward et al. [33] calls the argument of decoupling environmental impacts from economic growth appealing because it would justify GDP growth as a sustainable societal goal. In this light, decoupling became one of the major objectives of the Organization for Economic Cooperation and Development's (OECD) Environmental Strategy for the early 21st century [40], and has since been incorporated as a viable policy target in matters such as the SDGs [33]. Accordingly, many scholars consider decoupling of GDP from the use of natural resources and greenhouse gas emissions (GHGs) a prerequisite and logical necessity, if sustainability targets are to be achieved [35–39].

Even though the importance of water and the worsening situation surrounding the vital resource is clear, no comprehensive connection between the notion of decoupling and water withdrawal exists at the global level. The present study addresses this apparent literature gap by performing a decoupling analysis of water withdrawals from 1995 to 2075 for 155 countries. The motivations for this study are fourfold. First, there is a broad research base on the topic of water, including analysis of past, present, and future water withdrawals. However, decoupling appears to be a missing piece in this literature, as few studies specifically address decoupling of water withdrawals from GDP. Studies that do cover water decoupling tend to focus on the past or present, whereas this research offers a look into the future. Second, many water-related studies have a narrow or regional scope. However, given the increasing importance of global drivers including climate change, urbanization, globalization, and population growth, assessing the issue from a global country-level standpoint is essential [6,39,42,42]. Third, whether climate change or economic and population growth are the most influential factors driving future water stress is a contested topic in this field. Similarly, fourth, there is ongoing debate whether or not the inverted-U relationship between resources and GDP growth hypothesized by the Environmental Kuznets Curve (EKC) is evident for water withdrawals [43–45]. This study attempts to shed further light on these two discussions while comparing the impact of two different climate models and three shared socioeconomic pathway (SSP) scenarios [46]. Further evidence may result due to the fact that this analysis looks beyond 2050 until 2075, unlike most studies.

With the established importance and motivation, this study presents expected future decoupling trends for country-level water withdrawals and shows how decoupling differs across geographical location, climate conditions, and income group classifications.

The objective of this paper is to provide a quantitative analysis that fills evident holes in the literature on the future world water situation. This estimation is of high interest to water resource managers, policymakers, stakeholders in all industries, and societies across the globe [47–49]. It offers a chance to plan ahead for the forthcoming global water crisis and, thereby, try to avert the worst-case scenario. Namely, projecting these trajectories at the global country scale could be used to identify patterns of change, serve as a foundation for addressing future challenges, and highlight similarities and differences of water problems shared across the world [5].

Results suggest that water withdrawal decoupling is occurring and predicted to intensify throughout the course of the 21st century. While moderate decoupling levels are achieved by 2025 on average, these reach a higher average of above 0.67 (1 = highest) by 2055. In 2075, average decoupling factors (DF) lie above 0.77. Although the trend points toward a decoupling increase in the latter half of the century, countries like Bosnia, China, and Cambodia achieve high water withdrawal DFs as early as 2025, while some nations (El Salvador, Jamaica, Gambia, etc.) lag behind in this development, even in the long-run. Although higher-income countries are among the better performing countries in the short-term, lower-income nations tend to catch up until 2075, on average. South Asian countries are predicted to have the highest rates of water withdrawal decoupling whereas Latin America and Caribbean as well as Sub-Saharan Africa States will tend to struggle, on average. In line, the tropical climate zone will experience lower water withdrawal decoupling than others. Geographical location and climate conditions appear as more influential factors than income group classification when it comes to driving water withdrawal decoupling. GDP growth is more important than current clustering of countries as low- or high-income, for example. Presented findings yield little evidence that an inverted-U EKC relationship exists for country-level water withdrawals. Overall, the results point to where policymakers and other stakeholders may search for best practice cases while also shedding light on which countries or regions need the most assistance in improving their future water situation. Coping strategies for a more promising outlook are discussed, including technological improvements, better governance and collaboration, and virtual water trade.

The rest of the paper proceeds as follows. Section 2 reviews the existing literature on decoupling and on water withdrawals. In sequence, Section 3 cites the data applied in this research. Section 4 presents decoupling results. Section 5 examines what influences water withdrawal decoupling. Section 6 interprets the findings while Section 7 summarizes and concludes.

2. Literature review

2.1. Decoupling

Since the beginning of the century, decoupling has become a hotly debated topic in academic research and environmental policy-making. The most comprehensive look at this development is given by Wiedenhofer et al. [38] and Haberl et al. [39]. Their meta-analyses illustrate the mounting research on the decoupling issue but also the aforementioned missing link to water at the worldwide country-scale.

The authors find relative decoupling to be frequent for material use and GHG emissions. However, examples of long-term absolute decoupling are rare. For the few cases where absolute decoupling was observed, the authors warn against generalizing because of specific circumstances such as decreasing resource use during economic crises. Such trends are expected around global shock events like the global financial crisis of 2008 or the COVID-19 pandemic. The analyzed literature shows that a continuation of past and ongoing trends will not yield absolute reductions in environmental inputs like water or in GHG emissions [6,39,50–52]. Additionally, Jackson and Victor [53] establish that noticeable absolute decoupling falls short of the significant amount of decoupling necessary to meet the agreed climate and SDG objectives. Evidence found by the OECD [40] in their initial report was in line with Haberl et al. [39] on the topic of relative decoupling, which they also judged as widespread in OECD member countries.

Specifically on the issue at hand, Gilmont [41,54,55] highlighted three key mechanisms driving water resource decoupling: (1) economic decoupling, for instance a shift from an economy based on agriculture with substantial irrigated land toward other economic sectors through diversification or through other non-water related changes, (2) trade-based decoupling, such as virtual water trade through food imports, and (3) natural water decoupling, through improved technologies, recycling, and management. In this light, Israel and Spain are at the forefront, showing significant water resource decoupling through trade and non-natural resource substitution [50,54]. In addition, trade-based decoupling has been occurring since the early 1960s in the Middle East and North Africa (MENA) region, while further decoupling can be achieved by targeting the users who consume the most water [55].

Further water decoupling evidence is brought forth by the OECD [56] report. Since the 1980s, various OECD countries stabilized or reduced total and per capita water abstractions. In particular, a "strong decoupling of water consumption levels from income growth" can be discerned, as per capita water consumption decreased by 6.5% across OECD member countries whereas gross national product per capita grew by 36% [40, p.49]. The SDG 6 indicator progress report [9] offers a specific example in this regard. After 1980, water withdrawals in the United States remained constant until 2005 and decreased, thereafter, until 2010 [9]. Meanwhile, population and economic growth occurred over that time frame [9], suggesting that socioeconomic growth was decoupled from water withdrawals. Success in this area can be attributed to efficiency improvements in agricultural and manufacturing water withdrawals, making the sector less water-intensive through efficiency gains and recycling [40]. It has not been analyzed whether, how, and at which scale these past trends will evolve throughout the 21st century across the globe, a gap this research fills.

2.2. Water withdrawals and future predictions

The present paper builds on previous work by Alcamo et al. [17], who identified future long-term developments in global water resources with socioeconomic and climate change as the drivers. Other research also serves as a solid foundation in global water resource simulation [6,57–60]. While using similar input data and climate scenarios, the current assessment adds to this broad base by incorporating decoupling as well as varying SSP scenarios into the analysis.

The relationship between income as an important factor of water use has been well established [17,47,61,62]. Alcamo et al. [17] find that growing withdrawals in the domestic sector due to income growth are the principal cause of increasing water stress. In this regard, the income effect is five to eleven times stronger than the impact of population growth [17]. Thus, changing incomes will have a major influence on future water withdrawals and crises, justifying the focus on water in relation to GDP in this research.

Apart from income, climate change is often cited as another significant driver [19,20,22,23,59,63]. Specifically, Schewe et al. [22] predict that a global warming of two degrees Celsius will lead to an additional 15% of the world's population facing severe water resource decreases. Whether income or climate change is the dominant factor in the developments of the future water situation is open to conjecture. Differences in effects are attributed to geographical location [61], with some regions being hurt more by rising temperatures levels than others. The present study sheds further light on the discussion. No matter which variable leads the charge, the fact remains that due to rising living standards, global warming, and other influences, a large fraction of the population will be confronted with chronic or absolute water scarcity due to rapidly dwindling supplies. In turn, this poses huge challenges for societies to adapt proactively in order to be better prepared for impending water crises.

Many scholars have evidently shown that these crises are not only ongoing but also growing in size and magnitude. Nechifor and Winning [64] highlight various studies projecting the future water demand in the face of socioeconomic development. While Kummu et al. [5] review the historical development of water scarcity, Alcamo et al. [58], Arnell [59], Alcamo et al. [17], Menzel and Matovelle [61], Schewe et al. [22], Gosling and Arnell [23], among others, forecast potential increases in water scarcity. Emerging hot spots that will be under severe water stress in the 2050s include many areas in the MENA, southern Africa, northern China as well as the west coast and northeast of Latin America [17]. On the other hand, withdrawals are projected to stabilize or decrease in many industrialized nations due to per capita water use saturation, lower population growth, and technological innovations, especially in the agricultural sector [17]. This effect is not observed in developing countries until the second half of the century [17]. Although this broad literature base exists, few have specifically incorporated the decoupling concept when looking at the future water situation. In doing so, this research advances the state of understanding global water resources and their management.

2.3. The Environmental Kuznets Curve

Frequently discussed in studies evolving the use of natural resources and GDP is the Environmental Kuznets Curve (EKC). Following Kuznets' [65] discovery of an inverted-U relationship between the level of inequality and income per capita, similar associations were made between environmental pressures and economic growth, giving rise to the EKC. The hypothesis holds that income growth will increase the pressure on an environmental indicator or a natural resource until a certain tipping point, after which the trend reverses. In this regard, early studies were primarily focused on levels of pollution versus income [44,45], before more scholars attempted to find evidence of the inverted-U relationship between natural resources and income. However, the literature base on the EKC correlation of water withdrawals and income remains narrow. The first evidence on the inverted-U relationship on this topic was presented by Rock [66]. In sequence, Gleick [67], Cole [68], Katz [43], Gu et al. [69] and others have examined the topic in various ways. Results of these studies are somewhat conflicting, with some finding evidence of an inverted-U relationship (for example Katz [43],Cole [68]) while others do not (for example Gleick [67],Gu et al. [69]). In line with contrasting results from prior research, Katz [44] suggests that whether the EKC relationship exists for water withdrawals is highly dependent on not only the choice of datasets and methodology but also on country- or region-specific factors such as geography. Because of this, Katz [44],Duarte et al. [45] dismiss the EKC as a poor predictor for country-level patterns of water withdrawals, limiting its use as a tool for predicting and planning. Broader criticisms of the EKC also exist elsewhere in literature [70]. With no final judgment call made yet, the present paper delivers more input on this discussion.

3. Data

Water withdrawal data at the country-level is taken from the Center for Environmental Systems Research at the University of Kassel (http://watclim.cesr.de). Included in the dataset are the years 1995, 2025, 2055, and 2075. Due to lack of consistent and applicable country-level data, this dataset was chosen as the best available option. Water withdrawals per country are calculated using the WaterGAP 2.2 water use model. This is widely accepted as one of the best global hydrological models for research on water, and is frequently used in water-related studies [6,17,49,51,58,61]. It is also the key model to compute comprehensive long-term global or regional estimates of water withdrawals and availability [51,58]. WaterGAP projections depend on its parameter inputs, which were left unchanged from Alcamo et al. [6] and Alcamo et al. [58].

Data for the three SSP scenarios analyzed is taken from the SSP database (https://tntcat.iiasa.ac.at/SspDb) [46]. This included country-level GDP projections from 2010 until 2100. These GDP forecasts are differentiated by the relevant factors impacting economic growth such as demographic trends, education, globalization and trade openness, technology, etc. [46]. GDP data for the year 1995 is obtained from the World Bank database (https://data.worldbank.org).

Additional economic data for the control variables is also obtained from the World Bank database. These variables include the export share, defined as exports of goods and services as a percentage of GDP, the import share, defined similarly, as well as economic agriculture and industry shares, both represented by percentage of GDP. The share of agricultural land, referring to the share of land area that is arable, under permanent crops, and under permanent pastures, is also taken from the World Bank. Population projections are obtained from the same dataset as the water withdrawal data (http://watclim.cesr.de). The justification for including export and import shares separately is the following. Put simply, both shares can have a significant impact on water withdrawals within a country. A country whose economy heavily depends on exports will likely have higher water withdrawals in the sectors in which they produce the most exported goods, industry for example. On the other hand, having a large import share may mean that the given country has lower water withdrawals because they are outsourcing water withdrawals to the exporting

Table 1
Summary statistics of the pooled data.

	Mean	SD	Min	Max	Obs
GDP (Billion USD)	1,465.98	5,982.83	0.63	72,049.55	620
Water Withdrawal (m^3)	28,311.28	98,578.05	0.30	993,339.80	620
Pop. growth (%)	69.91	95.84	−39.02	481.28	620
Export share (%)	41.55	30.12	3.60	230.00	604
Import share (%)	45.90	26.04	11.50	194.00	604
Share of irrigated land (%)	39.93	21.35	0.54	80.77	620
Agriculture share (%)	10.53	10.92	0.00	58.93	620
Industry share (%)	27.66	11.40	2.38	66.20	620

Note: Data sources are mentioned in the text.

nations, since the water is withdrawn for production in the latter. This is reflected in [15, p. 454], as "many regions no longer depend solely on their local water resources but more and more on the combination of those with virtual water embedded in imports of water-intensive products". Hence, differences in supply chains can positively or negatively affect water withdrawals, and need to be controlled for to appropriately assess the development of water withdrawals and DFs over time. In similar fashion, agriculture and industry are two of the largest water-consuming sectors across the world. In countries which rely heavily on these two sectors, water withdrawals may increase disproportionately in relation to other nations not so dependent on agricultural and industrial production. To control for this potential distortion, agriculture and industry shares are included in the analysis.

All control variables except population growth are assumed to remain constant over the study period, primarily because no reliable projections for future values and indicators exist in these cases. This should be kept in mind when interpreting the results below, as export, import, agricultural, and industrial shares of GDP do tend to shift up and down over time. However, these minor shifts are not expected to cause major differences in the results, as the effect size of these variables on the DF is small and insignificant for some specifications.

Table 1 presents summary statistics for the variables in the pooled dataset.

3.1. Country classifications

The countries are clustered by several different classifications to assess where there are clustering of trends by different groups. Income groups are taken from the World Bank database for the year 2020 (https://data.worldbank.org). World Bank's regional classifications, centered around broad continents, are taken to represent geographically defined regions. Lastly, climate zones are defined through the field listing of the CIA World Factbook (https://www.cia.gov/library/publications/the-world-factbook). Due to a lack of observations in each climate zone, the original 10 climate zones are collapsed to four in the analysis. The varying country classifications are shown in Fig. 1.

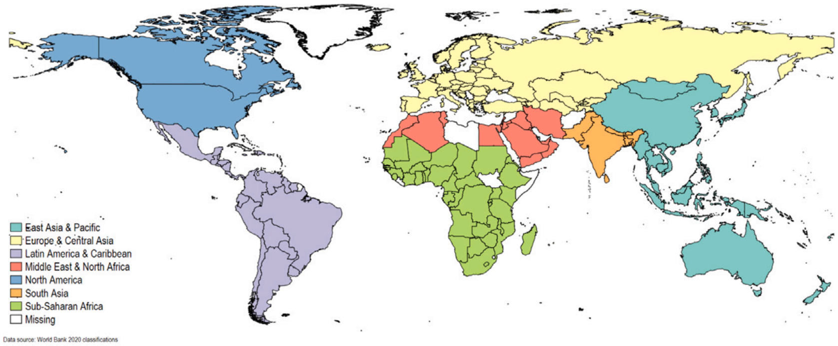
3.2. Water withdrawal scenarios A2 and B2

In this paper, the impact of driving forces on water withdrawal are assessed. Assumptions and water withdrawal projections come from the A2 and B2 scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) [71]. Two scenarios are applied to offset some of the high uncertainty of projections of water withdrawal drivers, as done by Alcamo et al. [17]. Together, they provide a broad range of estimates for important influential factors regarding water resources and absolute levels of future withdrawals [17].

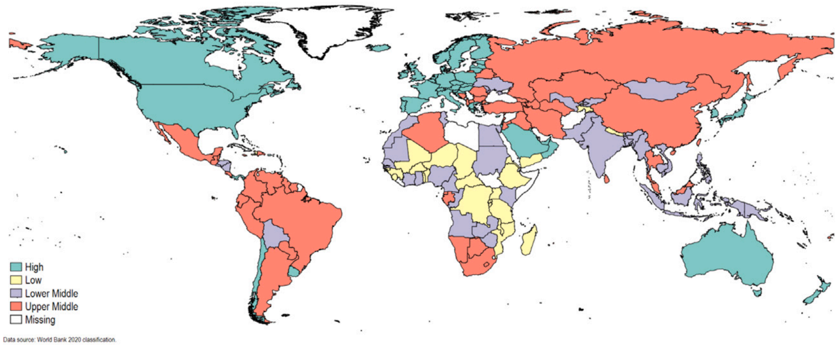
Scenario A2 exhibits low population growth, low to moderate economic growth, accompanied by high increase in GHG emissions and climate change [17]. However, in comparison to other IPCC scenarios, low levels of integration, trade, and technological diffusion are predicted. Alternatively, B2 forecasts higher economic growth, lower population, and a strong emphasis on non-climate-related environmental policies. As Alcamo et al. [17] highlight, this results in lower rates of climate change than under A2. Importantly, these assumptions result in Scenarios A2 projecting higher water withdrawals over time, on average, in comparison to Scenarios B2.

3.3. Climate scenarios

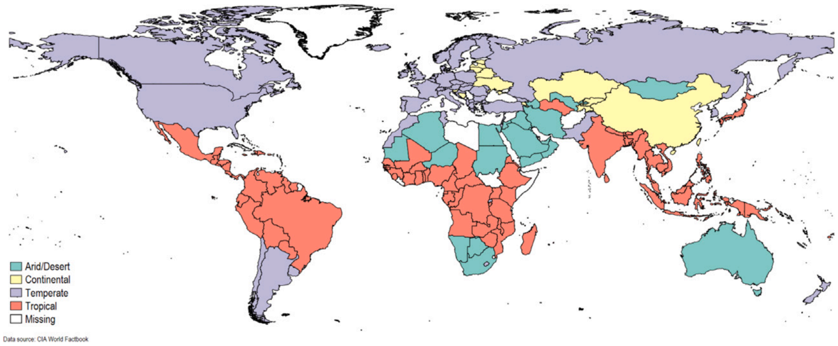
It is almost impossible to account for the high uncertainty regarding climate models. It is attempted here through the application of two different models: (1) the HadCM3 model of the Hadley Centre [72,73], and (2) the ECHAM4/OPYC3 model from the Max Planck Institute of Climatology [74,75]. The aforementioned sources give a detailed description of each climate model. In total, the ECHAM4/OPYC3 climate model forecasts slightly lower water withdrawals over time. The only difference between the two models is projected irrigation water withdrawals, which are higher for the HadCM3 model. Domestic, industrial, and livestock water withdrawals over time are the same for both climate models.



(a) Regions



(b) Income groups



(c) Climate zones

Fig. 1. Country classifications. Note: Data sources are mentioned in the text.

3.4. Shared Socioeconomic Pathways (SSPs)

As predicting the future state of the world in any matter comes with much uncertainty, the Shared Socioeconomic Pathways (SSPs) [76] framework has been adopted by various researchers. It offers a way to facilitate the integrated analysis of future climate impacts, socioeconomic development, resource use, adaptation, and mitigation. The framework was designed around a matrix combining climate forcing on one axis and socioeconomic conditions on the other. A total of five SSP narratives exists, providing descriptions of conceivable futures based on varying demographic, economic, lifestyle, policy, technological, institutional, and environmental changes [46]. The five narratives are: (SSP1) Sustainability, (SSP2) Middle of the Road, (SSP3) Fragmented World, (SSP4) Inequality, (SSP5) Conventional Development.

This analysis specifically focuses on SSP1, SSP2, and SSP5; in line with other literature on the topic [62]. In this research, the SSPs are used to apply three possible ways in which societies will develop economically. Hence, the major SSP input data are GDP projections over time. The different SSP forecasts are reflected by the DF differences produced by the three SSP scenarios. For a

Table 2
Summary of Shared Socioeconomic Pathway (SSP) scenarios.

Scenario	Summary
SSP1 — Sustainability	Good progress toward sustainability and SDGs Rapid development of low-income countries. Rapid technological developments. High environmental awareness. Consumption oriented toward low material growth and low levels of animal product consumption. Higher education, lower population growth. Universal access to water and clean energy are achieved in next two decades.
SSP2 — Middle of the road	Trends of recent decades continue Some progress toward SDGs and lower resource use. Low-income countries develop unevenly, with some being left behind entirely. Income grows at medium pace, on average (lowest GDP growth of the three SSPs). Slowly converging income levels between developing and industrialized nations. Population growth continues, especially in low-income countries. SDGs not achieved in the next few decades.
SSP5 — Conventional development	Conventional development focused on economic growth as the solution to social, economic, and environmental problems. Highest GDP growth of the three SSPs. Energy system primarily based on fossil fuels. SDGs attained through robust economic growth. Highly engineered infrastructure and ecosystems.

detailed description of the SSPs, see Moss et al. [77],O'Neill et al. [78], and the IIASA SSP database (https://tntcat.iiasa.ac.at/SspDb) with supplementary notes. Table 2 offers a summarized look at the most important points on the SSPs incorporated in this analysis [46]. The different input assumptions cause variations in GDP projections over time. In most cases, SSP5 results in the highest GDP growth for all years in the dataset, followed by SSP1, with SSP2 having the lowest GDP projections for 2025, 2055, and 2075.

4. Decoupling trends

Claims of a possible decoupling of GDP from resource use and environmental pressures were formulated as early as 1987, with UN [79] reporting on the world's common future. In sequence, building on the prior concept of 'eco-efficiency', decoupling was advanced by the Organisation for Economic Co-operation and Development (OECD) in 2001 and has since become a crucial concept in sustainable development. Specifically, decoupling "entails increasing the efficiency with which value is derived from natural resources in order to reconcile indefinite economic growth with environmental sustainability" [80, p.450]. As defined above, distinctions are made between absolute and relative decoupling. However, [55] argues that the differentiation between the two does not apply to water because global water resources are subject to spatial limitations instead of absolute scarcity. Additionally, resource decoupling must be distinguished from impact decoupling [37]. The latter concerns decoupling of GDP from GHG emissions, whereas the former addresses decoupling of GDP from energy or material use [39]. Hence, the present study focuses on resource decoupling. Gilmont [55] calls such decoupling analysis significant as it shows the political implications that decoupling has for resource use and security.

Decoupling is measured using a decoupling factor, which helps reveal long-term opportunities for progressing toward sustainable development [40]. To calculate the DF, we apply the following formula from the OECD [40]:

$$DF_{it} = 1 - \frac{(E/Y)_{it}}{(E/Y)_{i0}} \tag{1}$$

where E represents the environmental pressure, which in our case is percentage change in Water Withdrawal, and Y denotes the economic force which we measure using GDP Growth. The index denotes country i at time t. The calculation is done in absolute values and is referenced to the base period denoted by $t = 0$, which in our data is 1995. At best, the DF has a maximum value of 1, indicating absolute decoupling. A value in between 0 and 1 suggests that some decoupling has occurred during the period, whereas a negative value signals a coupling between the environmental pressure and GDP. Using the DF simplifies cross-country comparisons.

The OECD formula, like any other potential decoupling formula, does not come without critique. For example, Casadio Tarabusi and Guarini [81] highlight several weaknesses of the OECD formula such as its boundedness at 1 with there being no lower bound as well as and the difficulty of distinguishing between absolute and relative decoupling. Hence, the findings should be interpreted with some caution.

The use of three different SSPs (SSP1, SSP2, and SSP5), two different water withdrawal scenarios (A2 and B2), and two different climate models (HadCM3 and ECHAM-OPYC3), across three future time periods (2025, 2055, 2075) results in a total of 36 scenarios being analyzed.

Table 3
Summary statistics for average water withdrawal decoupling per scenario.

Model	Scenario	DF 2025	DF 2055	DF 2075
HadCM3 A2	SSP1	0.43	0.67	0.75
HadCM3 A2	SSP2	0.42	0.59	0.71
HadCM3 A2	SSP5	0.45	0.74	0.82
HadCM3 B2	SSP1	0.43	0.68	0.77
HadCM3 B2	SSP2	0.42	0.59	0.72
HadCM3 B2	SSP5	0.45	0.75	0.83
ECHAM-OPYC3 A2	SSP1	0.41	0.67	0.76
ECHAM-OPYC3 A2	SSP2	0.40	0.59	0.72
ECHAM-OPYC3 A2	SSP5	0.42	0.74	0.82
ECHAM-OPYC3 B2	SSP1	0.44	0.68	0.78
ECHAM-OPYC3 B2	SSP2	0.42	0.59	0.73
ECHAM-OPYC3 B2	SSP5	0.45	0.75	0.84
Average of all scenarios		0.43	0.67	0.77

Note: Decoupling factors (DF) are for total water withdrawals by country. Observations: 155. Mean values are reported for each scenario.

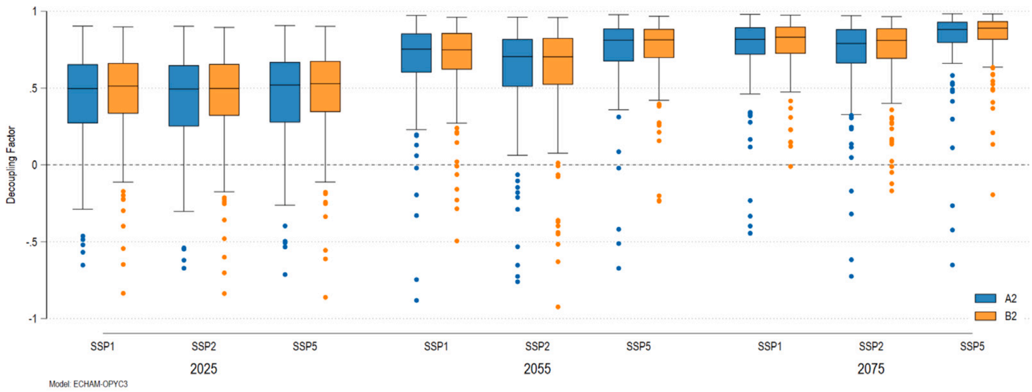
Table 3 presents the average water withdrawal decoupling for each scenario in the analysis. SSP5 (conventional development) scenarios consistently produce the highest DFs in each year. This does not come unexpected as GDP growth is the highest in SSP5, and the DF increases with higher rates of economic growth. Additionally, B2 scenarios typically generate higher DFs than their A2 counterparts, due to the fact that water withdrawal predictions are lower in B2 forecasts. ECHAM-OPYC3 scenarios yield higher decoupling results than HadCM3 models in most cases, granted that differences are small. The highest DFs in the second half of the century are produced by the ECHAM-OPYC3 B2 SSP5 scenario.

On average, water decoupling from GDP is relatively low until 2025, with a maximum average DF of 0.45. Fast forward 30 years, and decoupling intensifies, approaching values as high as 0.75. In 2075, decoupling is predicted to be common and widespread, with some scenarios yielding DFs over 0.80. It is encouraging, although not surprising, to see this upward trend in water withdrawal decoupling over the course of the 21st century. Major reasons for increased decoupling over time are likely improved technologies, greater water withdrawal efficiency, and GDP growth. However, even in 2075, one or more countries (depending on the scenario) will still have negative decoupling of water withdrawal, with the minimum DF value being −0.74 (Jamaica). In the years prior, several more countries are predicted to produce negative DFs. For example, Burundi has the lowest decoupling value for the year 2025, with −1.64 in the HadCM3 B2 SSP2 scenario. On the other hand, as early as 2025, some countries (Bosnia, China, etc.) experience extremely high water withdrawal decoupling with values above 0.89.

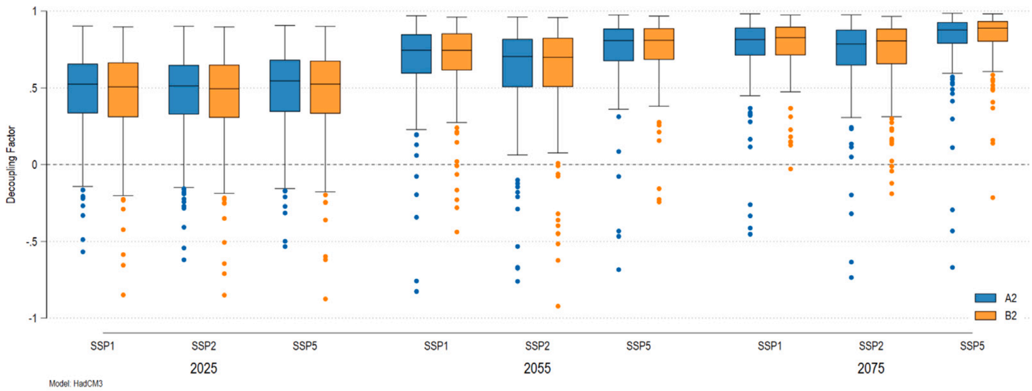
The underlying, calculated decoupling results form the basis for Figs. 2 and 3. These figures support the above-discussed summary statistics for average water withdrawal decoupling per Scenario in Table 3. Fig. 2 illustrates the DF distribution of each scenario. The box plots depict global median values together with 25th to 75th percentile ranges. Whiskers represent 1st and 99th percentiles while outliers are presented as dots. The figure shows that a lot of countries are still coupling in 2025 (below the 0 threshold). Over time, the positive trends are visible, as the number of countries decoupling water withdrawals from economic growth consistently increases. In this light, the global median values rise, the gap between the 25th and 75th percentile narrows, outliers become fewer, and many countries close the gap to those nations already producing high DFs as early as 2025. Yet, while some countries experience high water withdrawal decoupling, others continuously lag behind, with values below 0. Overall, the B2 scenarios paint the more optimistic picture with higher DFs over time.

For the remainder of the results section, only decoupling results from the ECHAM-OPYC3 SSP1 scenario are reported. The reasoning for this is that it produces medium to high outcomes while following a desirable SSP1 scenario path that makes good progress toward sustainability and the SDGs (see Table 2). Additionally, B2 is considered a best-case scenario in terms of societal and economic development as well as in respect to water withdrawal over time, as it projects lower resource use than its A2 counterpart.

Fig. 3 illustrates decoupling results by income groups, regions, and climate zones. Fig. 3a looks at the DF by income groups. Based on the B2 scenario, high and upper-middle-income countries perform better on average than countries on the lower-income spectrum in 2025. By 2055, lower-middle-income countries catch up with the higher-income nations while low-income countries still lag behind in terms of water withdrawal decoupling, when looking at median values. However, toward the end of the century, there is little separation between the various income groups and their average decoupling performance. In addition, the minimum and maximum decoupling values for each income group show that there are positive (high DFs) and negative (negative DFs) examples in every faction for almost all years. These trends hold for each SSP scenario. In all B2 scenarios, most income groups produce similar outcomes over time, with low-income countries catching up by 2075. This is not the case in A2 models. In fact, over time, low-income countries outperform higher-income nations in these scenarios. In A2 models, lower-income countries see relatively big rises in DFs in 2055 and 2075 in relation to the identical B2 models. On the other hand, higher-income countries have better DFs in B2 than in A2 scenarios. The main reason for this divergence is differences in water withdrawal projections between A2 and B2 models. While higher-income countries have lower levels of water withdrawal over time in B2 scenarios, A2 models forecast increases in water withdrawals. On the other hand, low-income countries have higher water withdrawals in B2 as opposed to A2 scenarios. Hence, lower-income nations have much lower DFs in B2 models, while higher-income countries perform better in these cases. The opposite applies in A2 scenarios.



(a) ECHAM-OPYC3



(b) HadCM3

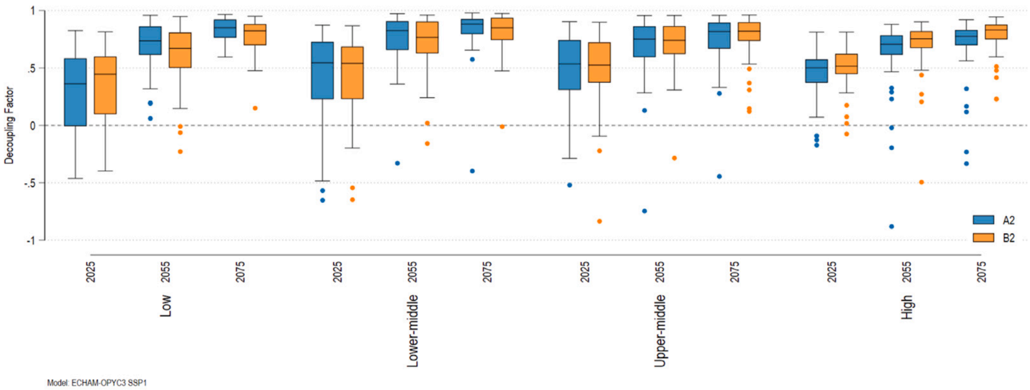
Fig. 2. Decoupling factor by scenarios.
Note: Decoupling factors are calculated from data sources mentioned in Section 3. Few countries with DF less than −1 are removed for clarity. Country-level details are given in the Appendix B.

The DFs by regions are shown in Fig. 3b. In the short-run, countries in Europe and Central Asia, North America, as well as South Asia produce the highest average DFs. On the other hand, Latin American and Caribbean and Sub-Saharan Africa perform by far the worst, on average. Although these regions catch up slowly over time, they do not reach the level of other regions by 2075. South Asian countries are the best water withdrawal decoupling performers throughout the century, on average.

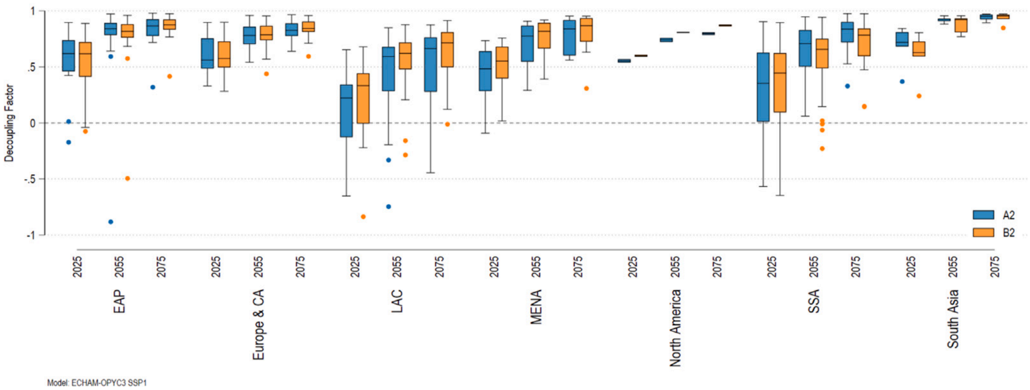
Fig. 3c shows the DF by climate zones. Here, it is worth noting that the continental climate zone continuously sees the highest water withdrawal decoupling averages in all scenarios. On the other hand, countries with rather tropical climate lag behind and exhibit the highest variance among each other throughout the century.

While the results above clustered decoupling averages based on scenarios, income groups, regions, and climate zones, DFs by individual country are listed in Appendix B. Specifically, a ranking system was created to better visualize the decoupling performance of each of the 155 countries in the analysis in relation to others. For each year in the study period, countries were assigned a rank from 1 to 155, with 1 indicating highest DF and 155 the opposite. Average ranks were calculated based on the individual country rank in each scenario.

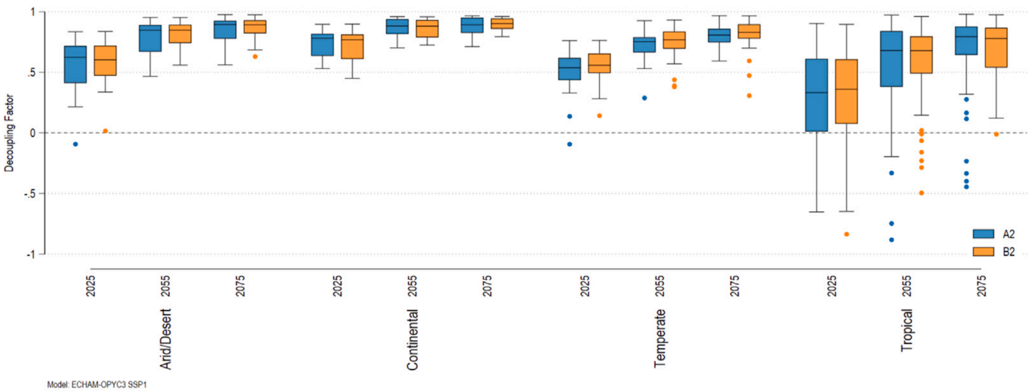
The key takeaway of the ranked results is that industrialized countries are not necessarily ranked higher than emerging or still developing nations when it comes to future water withdrawal decoupling. The main reason for this is likely the fact that the latter have higher rates of GDP growth in comparison to the former, which are already highly developed and experience slower rates of economic growth. This causes a ranking bias in favor of those countries with the highest projected GDP growths throughout the 21st century. In addition, countries performing well could be doing so because of water access issues. For example, countries like Turkmenistan, Kyrgyzstan, and Iraq, who all exhibit relatively high DFs throughout the 21st century, also face high water stress (see Fig. 5). This is concerning, because resource constraints could paint a misleading decoupling picture, such that high decoupling does not always represent a good thing.



(a) Income groups (HDI)



(b) Regions



(c) Climate zones

Fig. 3. Decoupling factor by different groups.
Note: Decoupling factors are calculated from data sources mentioned in Section 3. Few countries with DF less than −1 are removed for clarity. Country-level details are given in the Appendix B.

Fig. 4. Water withdrawal versus GDP. Note: Water withdrawal are measured in cubic meters. GDP is measured in Billion USD.

Hence, it is important to not only look at the DF but to complement it with an assessment of overall absolute trends in water withdrawals over time, to paint a clearer picture of the future world water situation. Absolute withdrawal reductions are mainly occurring in developed countries, and are more frequent in B2 scenarios. This could be another indication for increased water stress rather than more efficient water withdrawal and use. A more in-depth and wholesome look at these developments is required, beyond the findings of this research.

5. What impacts decoupling?

Past research has well-established the link between the use of water resources and economic development. To recap, growing GDP is one of the principal causes of increasing water withdrawals and stress [17,47,61,62]. The present study backs these findings. Fig. 4 shows the relationship of per capita water withdrawal and per capita GDP in natural log terms for all the data points from the four years 1995, 2025, 2050, and 2075. The figure shows a positive correlation between the two variables

This relationship is captured by the following regression model:

$$ln(Water_{percapita})_{it} = \beta_0 + \beta_1 ln(GDP_{percapita})_{it} + \beta_2 ln(GDP_{percapita})^2_{it} + \gamma_t + \beta_z z_{it} + \epsilon_{it} \quad (2)$$

where $Water\_pc_{it}$ represents the log of per capita water withdrawal in country i, in time t where time is represented by 1995, 2025, 2055, and 2075. The coefficients of interest in the first set of regressions are β_1 and β_2, the effect of log of per capita GDP and its squared term on per capita water withdrawal changes in a given country. Based on Fig. 4 β_1 is expected to be positive and significant, while β_2, if significant, is expected to be negative, implying declining water withdrawal requirements over time (relative decoupling). The worst-case scenario is β_2 being positive and significant, suggesting an acceleration of per capita withdrawal quantity with GDP (coupling).

For the variables, natural log-levels are used rather than growth terms. This is done for two reasons. First, countries are at different stages of development and, hence, growth rates for lower-income countries are expected to be higher relative to higher income countries since they have a lot of "catching up" to do. Second, high-income countries might have already achieved more efficient technologies that limit water withdrawals. Thus, the potential for change is smaller here as well. In contrast, developing countries might still benefit greatly from technological improvements.

Time fixed effects are represented by γ_t to factor out trends over time. Control variable z_{it} includes population growth, export, import, agricultural and industrial shares, and the share of agricultural land. Summary statistics for these variables are presented in Table 1. Countries are assumed to have an independent slope and intercept. Therefore, a fixed effects model is used. The variation not explained by these variables is captured by the error term ϵ_{it}.

Table 4 shows the results for various specifications of Eq. (2), all of which control for country fixed effects. All regressions depict that water withdrawal increases with GDP at a decreasing rate, which reinforces the prior results in suggesting that relative decoupling is occurring. This relationship holds across the different regression specifications after controlling for time fixed effects. Columns 4 and 5 add additional region and income fixed effects which results in a slight decline of the $ln(GDP\_pc)$ coefficient value, implying that income and regions also impact decoupling very differently. The EKC turning point was calculated by estimating the coefficients of the ln(GDP per capita) and its square terms, or β_1 and β_2 respectively. Since it is a quadratic function, the GDP values at which turning point happens is estimated as $-\beta_1/2\beta_2$. Since we know how the GDP of each country is developing in relation to

Table 4
Dependent variable: Ln(Water withdrawal per capita).

	(1)	(2)	(3)	(4)	(5)
Ln(GDP per cap.)	0.287***	1.939***	1.806***	1.209***	0.912***
	(0.032)	(0.213)	(0.240)	(0.408)	(0.301)
Ln(GDP per cap.)^2		−0.091***	−0.076***	−0.049**	−0.029*
		(0.011)	(0.015)	(0.022)	(0.017)
Observations	620	620	620	620	620
Adj. R2	0.36	0.48	0.51	0.53	0.64
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE			Yes	Yes	Yes
Year x Income				Yes	
Year x Region					Yes
Turning point (year)		2112	2241	2189	2283

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.1$.

Table 5
Dependent variable: Ln(Water withdrawal per capita).

	(1)	(2)	(3)	(4)
Ln(GDP per cap.)	1.593***	1.838***	1.857***	1.585***
	(0.325)	(0.243)	(0.233)	(0.336)
Ln(GDP per cap.)^2	−0.064***	−0.076***	−0.079***	−0.063***
	(0.019)	(0.015)	(0.014)	(0.020)
Pop. growth	0.001			0.001
	(0.001)			(0.001)
Export ratio		−0.008		−0.011
		(0.008)		(0.009)
Import ratio		0.001		0.003
		(0.009)		(0.009)
Share of agricultural land			0.011***	0.010**
			(0.004)	(0.004)
Agriculture dep.			−0.009	−0.019**
			(0.008)	(0.009)
Industry dep.			−0.003	−0.002
			(0.013)	(0.013)
Observations	620	604	620	604
R2	0.14	0.21	0.20	0.21
Year FE	Yes	Yes	Yes	Yes
Turning point (year)	2291	2292	2306	2292

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.1$.

time, we use linear trends to estimate which year the turning point will be achieved. Regardless of testing for various GDP forecasting measures, the turning points are mostly estimated to be too far in the future to comment on or use as an underlying assumption of a robust and predictable relationship in this case.

Table 5 shows Eq. (2) specification with controls added. Several factors play a role in water withdrawals changes. With increasing population growth, water withdrawals rise only marginally. Surprisingly, higher export shares result in a slight decline in water withdrawals. This could be attributed to high exporting countries already having better, less water-intensive technologies in place for the types of goods they are exporting. For instance, such countries may have implemented water-efficient irrigation or other technologies at a greater scale than countries who are not as dependent on exports. Additionally, these countries may focus on importing more water-intensive products, thereby, reducing their water withdrawals through virtual water trade. Imports do not impact decoupling, which is not surprising since imports embody withdrawals elsewhere. Having a higher share of agricultural land, unsurprisingly, increases withdrawals. The last column in Table 5 includes all controls to isolate their effects from the variable of interest.

Tables 6, 7, and 8 extend the analysis by exploring the impact of the control variables on withdrawals by region, income group, and climate zones. Each category is run separately to highlight which factors play a role in which region. For all the regressions, the full model specification shown in column 4 in Table 5 is used for the various scenarios.

The tables highlight that differences between varying regions and climate zones become more evident. For example, in Table 6, water withdrawals are positively correlated with GDP in all regions except in the MENA and East Asia and Pacific (EAP), where population growth is a bigger contributing factor to rising water withdrawals. All regions show decreasing returns relative to GDP, although some are not statistically significant. In Europe and Central Asia (ECA), water withdrawals are significantly driven by

Table 6
Dependent variable: Ln(Water withdrawal per capita) by regions.

	(1) EAP	(2) ECA	(3) LAC	(4) MENA	(5) S. Asia	(6) SSA
ln(GDP) per capita	0.459	1.333**	2.585***	0.412	2.851*	1.092*
	(0.484)	(0.518)	(0.644)	(0.849)	(1.724)	(0.573)
ln(GDP) per capita sq.	−0.027	−0.057*	−0.126***	−0.021	−0.139	−0.029
	(0.027)	(0.032)	(0.038)	(0.049)	(0.100)	(0.034)
Export ratio	0.083*	−0.020*	0.008	−0.005	0.104	−0.013
	(0.050)	(0.011)	(0.022)	(0.020)	(0.069)	(0.015)
Import ratio	−0.095*	0.019	−0.017	−0.038	−0.054***	0.007
	(0.053)	(0.013)	(0.020)	(0.025)	(0.016)	(0.008)
Pop. growth	0.005**	−0.010***	0.001	−0.004*	0.003	−0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.006)	(0.001)
Share of agricultural land	0.039***	0.012***	−0.010	0.007	0.010	−0.004
	(0.014)	(0.004)	(0.010)	(0.006)	(0.009)	(0.006)
Agriculture dep.	0.023	0.059***	−0.049	0.019	0.114***	0.002
	(0.035)	(0.014)	(0.055)	(0.054)	(0.026)	(0.010)
Industry dep.	−0.097***	0.040***	0.032*	0.032	−0.046	−0.017
	(0.036)	(0.013)	(0.017)	(0.020)	(0.055)	(0.014)
Observations	64	184	104	64	24	156
R2	0.59	0.45	0.33	0.75	0.91	0.53
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Turning point (year)	1601	1726	2633	2030	2363	2564

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.1$.

Table 7
Dependent variable: Ln(Water withdrawal per capita) by income groups.

	(1) Low	(2) Lower-middle	(3) Upper-middle	(4) High
ln(GDP) per capita	0.144	1.298*	−0.793	2.858***
	(1.074)	(0.750)	(0.933)	(0.845)
ln(GDP) per capita sq.	0.039	−0.061	0.057	−0.129***
	(0.074)	(0.050)	(0.056)	(0.041)
Export ratio	−0.021	0.020	−0.015	−0.049
	(0.030)	(0.046)	(0.039)	(0.039)
Import ratio	−0.001	−0.040	−0.044	0.021
	(0.017)	(0.032)	(0.039)	(0.046)
Pop. growth	0.005**	0.005***	0.006***	0.004***
	(0.002)	(0.001)	(0.002)	(0.001)
Share of agricultural land	−0.008	0.008	0.045***	0.044***
	(0.014)	(0.018)	(0.015)	(0.013)
Agriculture dep.	−0.018	0.002	−0.002	−0.195
	(0.020)	(0.045)	(0.078)	(0.257)
Industry dep.	0.023	−0.089*	0.053	−0.031
	(0.020)	(0.053)	(0.036)	(0.034)
Observations	96	140	176	192
R2	0.61	0.20	0.37	0.36
Year FE	Yes	Yes	Yes	Yes
Turning point (year)	2356	2512	2548	2355

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.1$.

agriculture and industry shares as well as the share of agricultural land. Furthermore, given the expected population decline in ECA, the sign is also negative. Agriculture and industry shares are mostly net positive contributors to withdrawals, while import and export shares reduce withdrawals across most regions. The EKC turning points have already been crossed in EAP and ECA, with the MENA being next. A clear divergence between a possible EKC relationship is evident between the various regions. This supports Katz [44], in that the EKC relationship is highly dependent on factors like geography, making it a controversial measure.

Table 7 shows the correlations of withdrawals by income groups. Interestingly, all but low-income nations show decreasing return to water withdrawals relative to GDP. Population growth contributes in all income groups, while lower-middle-income countries see a decline in withdrawals relative to industry share. The share of agricultural land is relevant for higher-income groups. Again, the EKC turning points are too far in the future to discuss with confidence.

Table 8
Dependent variable: Ln(Water withdrawal per capita) by climate zones.

	(1) Arid/Desert	(2) Continental	(3) Temperate	(4) Tropical
ln(GDP) per capita	0.528	1.219	2.388***	1.041*
	(0.411)	(0.976)	(0.539)	(0.540)
ln(GDP) per capita sq.	−0.011	−0.055	−0.103***	−0.044
	(0.023)	(0.052)	(0.034)	(0.031)
Export ratio	−0.024	−0.004	0.008	0.010
	(0.028)	(0.037)	(0.032)	(0.017)
Import ratio	−0.069**	−0.025	−0.054	−0.025*
	(0.031)	(0.034)	(0.038)	(0.014)
Pop. growth	0.004***	−0.001	0.003**	0.007***
	(0.001)	(0.004)	(0.001)	(0.001)
Share of agricultural land	0.010	0.041*	0.021	0.037***
	(0.013)	(0.022)	(0.017)	(0.012)
Agriculture dep.	0.055	0.081	−0.001	−0.019
	(0.035)	(0.087)	(0.067)	(0.020)
Industry dep.	0.055	0.161**	0.066	−0.007
	(0.036)	(0.071)	(0.050)	(0.027)
Observations	84	48	184	288
R2	0.52	0.83	0.43	0.23
Year FE	Yes	Yes	Yes	Yes
Turning point (year)	2063	4443	2196	2368

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.1$.

Table 8 illustrates the variations across the four climate zones. Water withdrawals are positively correlated with GDP at a decreasing rate in all climate zones. Population growth plays the most crucial role for all but the continental zone, where the share of agricultural land and the industrial share of GDP are more relevant. Further results are mixed with different factors affecting withdrawals.

6. Discussion

The above-discussed results present whether water withdrawal decoupling is occurring throughout the world, how water withdrawals are impacted by GDP growth, and which factors are the most influential in driving decoupling across specific income groups, regions, and climate zones. Altogether, they fulfill the objectives of this research, attempting to assess country-level water withdrawal decoupling trends and the connection to geographical location, climate, and income groups. Explaining why decoupling is happening in certain countries and not in others was beyond the scope of this analysis and input data.

The primary decoupling analysis portrays that water withdrawal decoupling intensifies throughout the 21st century. By 2075, water withdrawal decoupling is predicted to be common and widespread across the globe, averaging DFs as high as 0.86. Overall, SSP5 scenarios produce the highest average DFs due to their high economic growth projections, followed by SSP1 with sustainable development at its core. The findings add to the existing literature on decoupling, suggesting that long-term water withdrawal decoupling is possible and projected for the 21st century.

Short-run projections have higher-income countries experiencing more water withdrawal decoupling than lower-income countries. The latter are projected to bridge the gap and catch up until 2075. In fact, lower-income nations actually outperform higher-income nations, in regard to average DFs, in all A2 scenarios by the end of the study period. When ranking all countries based on their decoupling scores (see Appendix B), industrialized countries are not necessarily ranked higher than emerging or developing nations. Regional differences exist, as countries in Europe and Central Asia, North America, and South Asia produce the highest average DFs. Latin American and Caribbean as well as Sub-Saharan Africa lag behind overall decoupling trends.

Regional location and climate zone are strongly associated with and appear as important drivers of country-level water withdrawal decoupling outcomes. Contrarily, income group differences only play a role in the short-run, with higher-income nations averaging higher rates of decoupling. However, by 2075, this disparity becomes negligible, as lower-income countries catch up. In this light, overall GDP growth seems to be a more important factor than initial country-level income clusters.

Various scholars have identified the MENA, southern Africa, and Latin America as emerging hot spots facing severe water stress by 2050 (see Sections 2 and 5). Unfortunately, these three regions were also identified as those with the lowest average water withdrawal decoupling across all continental regions (see Fig. 3). Placing increased attention on trying to generate greater water withdrawal decoupling through the below-discussed coping strategies offers policymakers in these regions a chance to proactively fight the impending crises. Higher decoupling would help avert worst-case water stress scenarios. To visualize this relationship, Fig. 5 illustrates countries' DFs and their water stress levels. However, water withdrawal decoupling is very country-context-specific. Decoupling means different things for each country, and it is not entirely clear why it is happening for some and not for others. High DFs could, for example, result simply because access to water is an issue. In this light, limited water withdrawals due to a lack

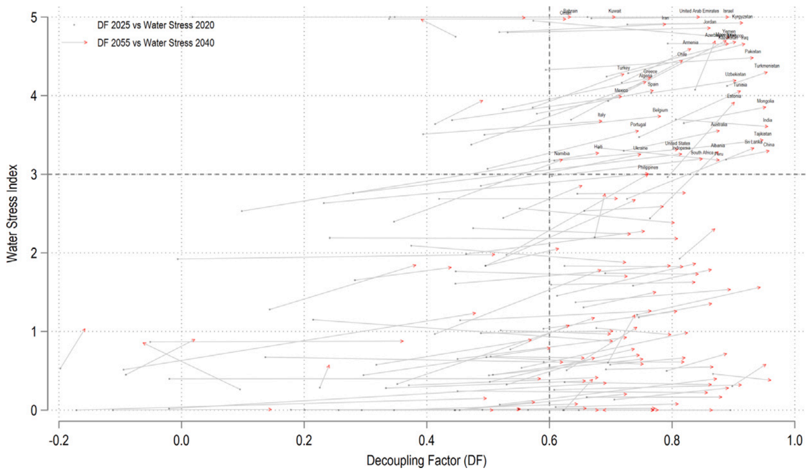


Fig. 5. Decoupling factor and water stress.
Note: DF less than −0.2 dropped from graphs for visibility. Water stress data is taken from the World Resources Institute (https://www.wri.org).

of the resource in the first place could result in misleadingly high water withdrawal DFs. This is a concerning scenario, exposing countries in the top right quadrant to high risk in relation to future water resources.

Thus, it is not only important to achieve greater efficiency in relation to water resources but to also keep track of absolute volumes of withdrawn water. Instances where absolute water withdrawal volumes decrease are mainly predicted to occur in developed countries, and more frequently in B2 scenarios. These trends need to be included in the bigger picture. Further, this research attempted to shed more light on the ongoing discussion of a possible EKC relationship between water and GDP. However, signs do not point toward an evident, robust inverted-U relationship for water withdrawals and income at the country-level, limiting the usefulness of the EKC assumption in this regard.

6.1. Discussion on coping strategies

Two important questions remain unanswered: how can the presented information be used and how can countries and regions struggling to make meaningful progress toward greater water withdrawal decoupling be guided toward the right direction?

First, the analysis highlights that positive examples for water withdrawal decoupling exist across all income groups, regions, and climate zones as early as 2025. These should serve as best practice cases for struggling nations to aspire to. For instance, Croatia can look to its neighbor Bosnia to create equivalent long-term water withdrawal decoupling success. In this light, countries like Croatia could specifically assess how and with what means Bosnia and others are achieving desired water withdrawal decoupling. Similarly, even entire regions like the Latin America and the Caribbean may model themselves after thriving regions like South Asia. In this regard, having projected DFs throughout the 21st century laid out allows policymakers to collaborate proactively and change the course of the future world water situation.

The fact that decoupling becomes common and widespread over time is an indicator for more efficient technologies paving the way toward greater water withdrawal productivity. Improved efficiency is also possible through water policy reforms as suggested by Rosegrant et al. [82] and more intelligently coordinated distribution [83]. Additionally, increased research funding and better water system infrastructure can lead to advances in agricultural production per unit of water or water conservation efforts, for example Wallat [83]. For this purpose, governments, industry, and researchers need to work together, collect information, and openly share data [12,84]. Being a collective action problem [27], collaboration, stakeholder engagement, and regional water management solutions are essential in improving the outlook on looming water crises [85].

Many important projects on water are ongoing. They range from new solutions on water supply, technological innovations, flood management, climate change impacts, to water resource and reuse management [12]. In this light, wastewater transformations are recognized as a major opportunity to alter water resource management and present several ways of curbing water withdrawals. Yet, it must be acknowledged that strategies to cope with worsening water situations are regionally dependent. For instance, short-, medium-, and long-run actions can be specifically tailored to Sub-Saharan Africa [86]. Following the suggestions of these authors could cause Sub-Saharan Africa to see an increase in long-term water withdrawal decoupling. Additionally, not all regions may be able to diversify their economy due to climate conditions and, thus, have to concentrate on other efforts. A more global approach could rely on expanded virtual water trade. Among others, [55] has identified virtual water trade as a way of alleviating national water limits. Porkka et al. [15] highlight reduced exports of water-intensive products as an option to reduce pressure on water resources, along with more traditional hard and soft measures. Alternatively, countries who have insufficient technologies may favor a switch to more imports of water-intensive goods which can be produced more efficiently elsewhere [15].

All the above strategies represent viable solutions to curb impending water crises around the world, built on the mechanisms driving decoupling introduced by Gilmont [41,54,55]. In this way, they would not only decrease their absolute water withdrawals but also increase water withdrawal decoupling, a meaningful measure en route toward achieving the SDGs and overall sustainability. It is recommended that policymakers and other stakeholders act today instead of tomorrow.

7. Conclusions

The world water situation is becoming increasingly worse, with more and more countries experiencing water stress and shortages. This no longer primarily applies to developing countries but is happening all across the world. Even the world's leading nations are predicted to encounter water shortages under business-as-usual forecasts, with [83] citing Germany as an example. The looming crises make sustainable water management a more pressing need now than ever before. In this regard, placing increased importance on decoupling water withdrawal from economic growth offers a viable solution for local, regional, and global policymakers. For this reason, the present study attempted to shed light on this topic, which was identified as an evident gap in the current literature base, by assessing 21st century water withdrawal decoupling projections in 155 countries.

In sum, water withdrawal decoupling is predicted to increase throughout the course of the century and will become common and widespread by 2075, although some countries will seemingly be left behind in this development. These are predominantly located in Latin America and the Caribbean as well as Sub-Saharan Africa. However, when ranking all countries based on their water withdrawal DFs, industrialized nations are not necessarily ranked higher than emerging or still developing countries. In fact, many of the latter rank among the top, especially toward the end of the study period. This is likely due to high projected GDP growth in relation to 1995, in comparison with current high-income nations who do not experience rapid economic growth anymore. Thus, overall GDP growth is more important in driving high DFs than current income group designations. In addition, country-specific climate zone and regional location appear to have greater impacts on water withdrawal decoupling than income group classifications. It is also clear that the importance and significance of the various influential drivers varies among and within the different income groups, regions, or climate zones. This is one of the reasons why we found little evidence in support of a possible EKC relationship between water withdrawals and GDP at the country-level, putting the usefulness of the EKC assumption for country-level water withdrawals into question. The calculated EKC turning points were mostly too far in the future to point toward a robust and clear inverted-U relationship.

Projecting water withdrawal decoupling at the global scale allows for the identification of best practices by countries who already produce high DFs, for diagnosing problems in regions who are lagging behind, and for pinpointing patterns of change. These and more can be the starting point for future research. Additionally, to paint a clearer picture, DFs need to be complemented by holistic assessments of absolute water withdrawal reductions. In-depth analyses should look into explaining why decoupling is occurring in certain areas but not in others, and specifically lay out best practices.

Impending water crises across the globe can be tackled through many measures, including technological advances, water policy reforms, collaboration in governance and science, wastewater transformations, virtual water trade, etc. Insights into the trends and influential drivers of future water withdrawal decoupling from this study are hoped to provide input into the proper implementation of effective coping strategies for a better outlook on the world water situation. In this way, decoupling provides a pathway to a more water-wise world.

CRediT authorship contribution statement

Felix Dalstein: Conceptualization, Methodology, Formal Analysis, Resources, Writing, Project Administration. **Asjad Naqvi:** Methodology, Validation, Formal Analysis, Investigation, Data curation, Visualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Decoupling zones

Fig. A.6 shows decoupling zones as defined in Tapio [87], Casadio Tarabusi and Guarini [81], Naqvi and Zwickl [88]. This figure provides a better representation of how the water withdrawal rate will develop over time with respect to changes in GDP.

The values of the different zones are calculated for each country for the last time period and displayed in Fig. A.7. While there are six broad zones, as shown in Fig. A.6, between 2025 and 2075 all countries are expected to grow. Hence, the negative axes has been trimmed for visibility. On the positive growth side, the three possible scenarios have been highlighted in the figure: absolute decoupling, relative decoupling, and coupling. In the last case, water withdrawals increase faster than GDP growth. Countries in this zone and a few countries close the red 45 degree line in the relative decoupling zone are spotlighted in the figure.

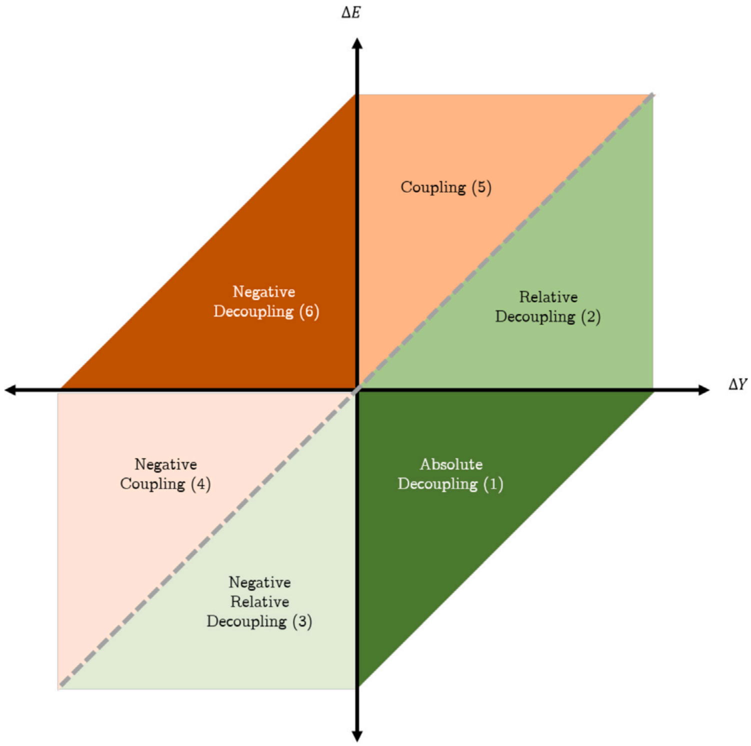


Fig. A.6. Decoupling zones.
Source: Adapted from Tapio [87], Naqvi and Zwickl [88].

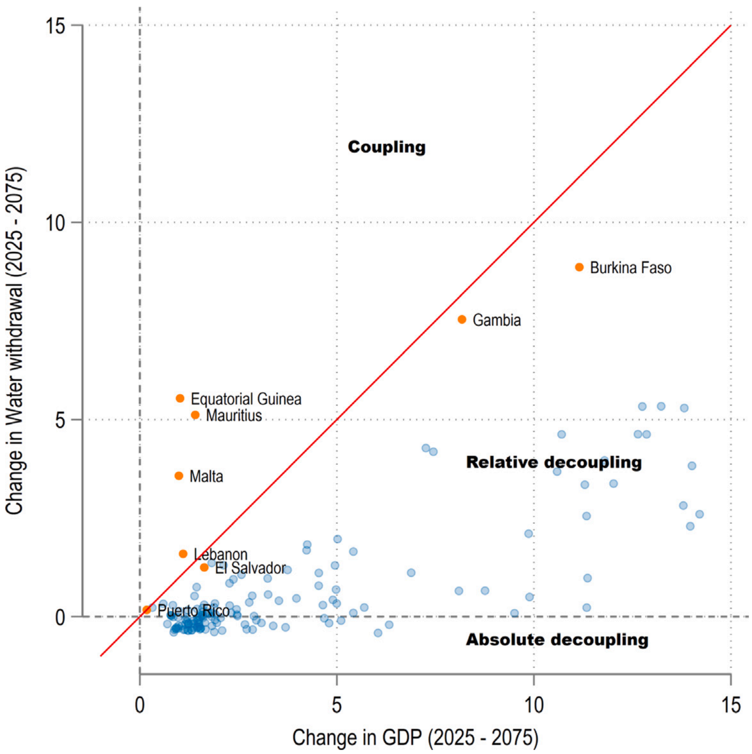


Fig. A.7. Decoupling zones.

Appendix B. Country rankings

See Table B.9.

Table B.9
Country rankings.

Country	Region	Income group	Climate zone	DF 2025	Rank 2025	DF 2055	Rank 2055	DF 2075	Rank 2075	Water Stress 2020	Water Stress 2040
Albania	ECA	Upper Middle	Temperate	0.764	15	0.875	29	0.904	37	2.44	3.28
Algeria	MENA	Upper Middle	Arid/Desert	0.472	91	0.757	74	0.852	60	3.38	4.17
Angola	SSA	Lower Middle	Tropical	0.695	30	0.739	83	0.821	85	0.61	1.21
Argentina	LAC	Upper Middle	Temperate	0.420	104	0.710	92	0.780	101	2.69	2.69
Armenia	ECA	Upper Middle	Continental	0.718	26	0.830	45	0.876	51	4.16	4.60
Australia	EAP	High	Arid/Desert	0.721	25	0.877	27	0.921	25	3.30	3.55
Austria	ECA	High	Temperate	0.501	81	0.752	77	0.818	86	0.44	0.65
Azerbaijan	ECA	Upper Middle	Arid/Desert	0.837	6	0.870	31	0.918	28	4.08	4.69
Bahamas	LAC	High	Tropical	0.075	135	0.206	147	0.229	151		
Bahrain	MENA	High	Arid/Desert	0.018	136	0.634	114	0.749	115	5.00	5.00
Bangladesh	South Asia	Lower Middle	Tropical	0.608	55	0.913	13	0.957	9	0.26	0.32
Barbados	LAC	High	Tropical	0.309	118	0.481	135	0.514	139		
Belarus	ECA	Upper Middle	Continental	0.746	18	0.864	35	0.899	39	1.18	1.35
Belgium	ECA	High	Temperate	0.494	86	0.781	63	0.844	67	3.50	3.74
Belize	LAC	Upper Middle	Tropical	0.371	109	0.679	105	0.813	89	0.32	0.41
Benin	SSA	Low	Tropical	−0.112	145	0.146	148	0.536	137	0.00	0.01
Bhutan	South Asia	Lower Middle	Tropical	0.648	43	0.770	68	0.849	62	0.00	0.00
Bolivia	LAC	Lower Middle	Tropical	0.297	119	0.601	120	0.618	131	0.44	0.79
Bosnia And Herzegovina	ECA	Upper Middle	Continental	0.898	1	0.953	5	0.959	7	0.30	0.58
Botswana	SSA	Upper Middle	Arid/Desert	0.530	72	0.760	73	0.823	84	1.97	3.00
Brazil	LAC	Upper Middle	Tropical	−0.051	141	0.361	141	0.545	134	0.87	0.88
Brunei Darussalam	EAP	High	Tropical	−0.074	142	−0.494	155	0.417	147	0.00	0.01
Bulgaria	ECA	Upper Middle	Temperate	0.447	99	0.797	59	0.827	81	1.61	1.84
Burkina Faso	SSA	Low	Tropical	0.624	50	0.670	108	0.697	124	0.00	0.39
Burundi	SSA	Low	Tropical	−1.496	155	−0.228	153	0.538	136	0.00	0.30
Cambodia	EAP	Lower Middle	Tropical	0.867	5	0.961	1	0.974	2	0.46	0.38
Cameroon	SSA	Lower Middle	Tropical	0.178	129	0.551	127	0.780	102	0.01	0.01
Canada	North America	High	Temperate	0.590	60	0.807	56	0.878	50	1.04	1.26
Central African Republic	SSA	Low	Tropical	−0.225	149	0.215	146	0.684	127	0.00	0.00
Chad	SSA	Low	Tropical	0.699	28	0.821	48	0.867	56	0.58	0.67
Chile	LAC	High	Temperate	0.635	46	0.816	51	0.852	61	3.69	4.45
China	EAP	Upper Middle	Continental	0.888	4	0.958	2	0.961	6	3.19	3.30
Colombia	LAC	Upper Middle	Tropical	0.333	116	0.658	110	0.785	99	0.28	0.37
Congo	SSA	Lower Middle	Tropical	0.256	123	0.679	104	0.781	100	0.00	0.00
Costa Rica	LAC	Upper Middle	Tropical	0.520	75	0.699	96	0.768	108	1.01	0.97
Côte d'Ivoire	SSA	Lower Middle	Tropical	−0.021	139	0.692	98	0.826	82	0.02	0.34
Croatia	ECA	High	Temperate	0.530	71	0.673	106	0.765	110	0.32	0.66
Cyprus	ECA	High	Temperate	0.559	65	0.793	60	0.870	53		
Czech Republic	ECA	High	Temperate	0.283	121	0.439	138	0.596	132	1.65	1.81
Dem. Rep. of Congo	SSA	Low	Tropical	−0.172	146	0.497	133	0.540	135	0.00	0.15
Denmark	ECA	High	Temperate	0.508	78	0.746	79	0.817	87	0.45	0.70
Dominican Republic	LAC	Upper Middle	Tropical	0.413	105	0.491	134	0.534	138	3.64	3.94
Ecuador	LAC	Upper Middle	Tropical	0.375	108	0.724	89	0.835	74	2.09	1.88
Egypt	MENA	Lower Middle	Arid/Desert	0.643	45	0.895	18	0.936	17	1.37	1.53
El Salvador	LAC	Lower Middle	Tropical	−0.198	147	−0.158	152	−0.010	155	0.53	1.03
Equatorial Guinea	SSA	Upper Middle	Tropical	0.895	2	0.688	100	0.660	128	0.00	0.00
Eritrea	SSA	Low	Tropical	−0.398	151	0.501	132	0.836	73	3.64	3.00
Estonia	ECA	High	Continental	0.793	12	0.901	17	0.934	19	2.96	3.91
Ethiopia	SSA	Low	Tropical	0.504	79	0.656	111	0.833	75	0.68	0.66
Fiji	EAP	Upper Middle	Tropical	−0.040	140	0.576	122	0.767	109		
Finland	ECA	High	Temperate	0.612	52	0.838	43	0.892	43	1.45	1.86
France	ECA	High	Temperate	0.464	92	0.755	75	0.831	77	1.98	2.28
Gabon	SSA	Upper Middle	Tropical	0.294	120	0.508	130	0.493	142	0.00	0.00
Gambia	SSA	Low	Tropical	0.095	134	−0.063	151	0.150	152	0.26	0.85
Georgia	ECA	Upper Middle	Temperate	0.674	36	0.690	99	0.758	113	2.20	2.75
Germany	ECA	High	Temperate	0.447	97	0.727	86	0.798	94	1.76	1.70
Ghana	SSA	Lower Middle	Tropical	0.225	126	0.241	145	0.507	140	0.29	0.57
Greece	ECA	High	Temperate	0.524	74	0.765	71	0.828	80	3.83	4.23
Guatemala	LAC	Upper Middle	Tropical	−0.095	144	0.479	136	0.582	133	0.51	1.23

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Table B.9 (*continued*).

Country	Region	Income group	Climate zone	DF 2025	Rank 2025	DF 2055	Rank 2055	DF 2075	Rank 2075	Water Stress 2020	Water Stress 2040
Guinea	SSA	Low	Tropical	0.550	68	0.772	66	0.867	55	0.01	0.02
Guinea-Bissau	SSA	Low	Tropical	0.445	101	0.770	67	0.837	72	0.00	0.00
Guyana	LAC	Upper Middle	Tropical	0.137	132	0.621	117	0.714	119	0.67	0.61
Haiti	LAC	Low	Tropical	0.098	133	0.680	103	0.741	116	2.53	3.27
Honduras	LAC	Lower Middle	Tropical	0.352	110	0.673	107	0.715	118	0.33	1.17
Hong Kong	EAP	High	Tropical	0.732	21	0.887	25	0.913	30		
Hungary	ECA	High	Temperate	0.318	117	0.570	124	0.724	117	0.58	0.89
Iceland	ECA	High	Temperate	0.622	51	0.865	34	0.920	27	0.00	0.00
India	South Asia	Lower Middle	Tropical	0.806	10	0.956	3	0.972	3	3.70	3.61
Indonesia	EAP	Lower Middle	Tropical	0.280	122	0.815	52	0.879	49	2.76	3.26
Iran	MENA	Upper Middle	Arid/Desert	0.518	77	0.789	61	0.846	66		
Iraq	MENA	Upper Middle	Arid/Desert	0.728	22	0.918	11	0.953	10	4.28	4.66
Ireland	ECA	High	Temperate	0.691	33	0.842	42	0.902	38	1.74	1.73
Israel	MENA	High	Temperate	0.668	37	0.892	20	0.944	14	4.98	5.00
Italy	ECA	High	Temperate	0.394	107	0.685	101	0.780	103	3.51	3.67
Jamaica	LAC	Upper Middle	Tropical	−0.835	154	−0.285	154	0.122	154		
Japan	EAP	High	Tropical	0.476	90	0.732	85	0.833	76	2.31	2.24
Jordan	MENA	Upper Middle	Arid/Desert	0.532	70	0.862	38	0.892	42	4.80	4.86
Kazakhstan	ECA	Upper Middle	Continental	0.793	11	0.892	21	0.907	35	4.66	4.66
Kenya	SSA	Lower Middle	Tropical	−0.647	153	0.503	131	0.772	105	0.44	0.64
Kuwait	MENA	High	Arid/Desert	0.340	114	0.707	93	0.763	111	5.00	5.00
Kyrgyzstan	ECA	Lower Middle	Continental	0.727	23	0.915	12	0.938	16	4.90	4.93
Laos	EAP	Lower Middle	Tropical	0.610	53	0.810	53	0.873	52	0.04	0.08
Latvia	ECA	High	Continental	0.450	96	0.725	88	0.796	95	0.65	0.92
Lebanon	MENA	Upper Middle	Temperate	0.447	98	0.391	139	0.309	149	4.75	4.97
Lesotho	SSA	Lower Middle	Temperate	0.144	131	0.382	140	0.475	146	1.28	1.84
Lithuania	ECA	High	Continental	0.812	9	0.869	32	0.891	45	1.93	2.30
Luxembourg	ECA	High	Temperate	0.645	44	0.821	47	0.861	59	2.75	2.76
Macedonia	ECA	Upper Middle	Temperate	0.696	29	0.888	24	0.912	32		
Madagascar	SSA	Low	Tropical	0.215	127	0.702	95	0.882	47	1.15	0.88
Malawi	SSA	Low	Tropical	0.347	112	0.646	113	0.757	114	0.00	0.08
Malaysia	EAP	Upper Middle	Tropical	0.413	106	0.683	102	0.771	106	0.97	1.78
Mali	SSA	Low	Tropical	0.625	48	0.864	37	0.912	33	0.36	0.32
Malta	MENA	High	Temperate	0.758	16	0.696	97	0.701	123		
Mauritania	SSA	Lower Middle	Arid/Desert	0.628	47	0.742	81	0.848	64	0.51	1.05
Mauritius	SSA	Upper Middle	Tropical	0.665	38	0.479	137	0.146	153		
Mexico	LAC	Upper Middle	Tropical	0.441	103	0.717	91	0.788	96	3.69	3.99
Moldova	ECA	Lower Middle	Temperate	0.525	73	0.653	112	0.714	120	2.45	2.85
Mongolia	EAP	Lower Middle	Arid/Desert	0.819	7	0.952	6	0.966	4	3.65	3.85
Morocco	MENA	Lower Middle	Temperate	0.693	31	0.903	16	0.940	15	4.24	4.68
Mozambique	SSA	Low	Tropical	0.791	13	0.889	23	0.907	36	0.50	0.72
Myanmar	EAP	Lower Middle	Tropical	0.661	40	0.881	26	0.945	13	0.17	0.17
Namibia	SSA	Upper Middle	Arid/Desert	0.347	113	0.621	118	0.763	112	2.40	3.18
Nepal	South Asia	Low	Tropical	0.242	124	0.809	55	0.927	22	2.19	2.18
Netherlands	ECA	High	Temperate	0.496	85	0.739	82	0.812	90	1.83	2.67
New Zealand	EAP	High	Temperate	0.591	59	0.819	49	0.908	34	0.61	0.61
Nicaragua	LAC	Lower Middle	Tropical	−0.020	138	0.585	121	0.498	141	0.40	0.40
Niger	SSA	Low	Arid/Desert	0.706	27	0.891	22	0.935	18	0.13	0.28
Nigeria	SSA	Lower Middle	Tropical	−0.091	143	0.021	149	0.476	145	0.45	0.90
Norway	ECA	High	Temperate	0.692	32	0.866	33	0.912	31	0.52	0.55
Oman	MENA	High	Arid/Desert	0.338	115	0.627	116	0.686	126	4.98	4.97
Pakistan	South Asia	Lower Middle	Temperate	0.594	58	0.932	10	0.966	5	4.33	4.48
Panama	LAC	High	Tropical	0.565	64	0.777	64	0.830	79	0.00	0.00
Papua New Guinea	EAP	Lower Middle	Tropical	0.519	76	0.872	30	0.923	23	0.07	0.40
Paraguay	LAC	Upper Middle	Tropical	−0.222	148	0.308	143	0.370	148	0.00	0.00
Peru	LAC	Upper Middle	Tropical	0.680	34	0.876	28	0.914	29	3.34	3.18
Philippines	EAP	Lower Middle	Tropical	0.232	125	0.761	72	0.870	54	2.63	3.01
Poland	ECA	High	Temperate	0.496	84	0.615	119	0.711	121	1.84	2.05
Portugal	ECA	High	Temperate	0.499	82	0.745	80	0.831	78	3.07	3.55
Puerto Rico	LAC	High	Tropical	0.175	130	0.272	144	0.231	150		
Republic of Korea	EAP	High	Temperate	0.657	41	0.785	62	0.809	92	2.53	2.59
Romania	ECA	Upper Middle	Temperate	0.656	42	0.773	65	0.816	88	1.31	1.50
Russian Federation	ECA	Upper Middle	Temperate	0.736	20	0.864	36	0.896	41	1.58	1.79
Rwanda	SSA	Low	Temperate	0.446	100	0.576	123	0.804	93	0.00	0.10

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Table B.9 (*continued*).

Country	Region	Income group	Climate zone	DF 2025	Rank 2025	DF 2055	Rank 2055	DF 2075	Rank 2075	Water Stress 2020	Water Stress 2040
Saudi Arabia	MENA	High	Arid/Desert	0.348	111	0.560	125	0.632	130	5.00	4.99
Senegal	SSA	Lower Middle	Tropical	0.554	66	0.825	46	0.922	24	0.54	0.98
Sierra Leone	SSA	Low	Tropical	0.491	87	0.659	109	0.769	107	0.00	0.02
Slovakia	ECA	High	Temperate	0.536	69	0.632	115	0.710	122	0.77	1.08
Slovenia	ECA	High	Continental	0.503	80	0.738	84	0.842	68	0.36	0.78
South Africa	SSA	Upper Middle	Arid/Desert	0.604	56	0.849	40	0.891	44	2.98	3.19
Spain	ECA	High	Temperate	0.579	61	0.769	69	0.841	69	3.77	4.07
Sri Lanka	South Asia	Upper Middle	Tropical	0.726	24	0.933	9	0.952	11	2.69	3.33
Sudan	SSA	Lower Middle	Arid/Desert	0.743	19	0.943	8	0.975	1	1.21	1.56
Suriname	LAC	Upper Middle	Tropical	0.450	95	0.857	39	0.884	46	0.24	0.22
Sweden	ECA	High	Temperate	0.603	57	0.837	44	0.896	40	1.60	1.63
Switzerland	ECA	High	Temperate	0.454	93	0.765	70	0.841	70	1.14	1.26
Tajikistan	ECA	Low	Continental	0.815	8	0.948	7	0.950	12	3.31	3.44
Tanzania	SSA	Low	Tropical	0.488	88	0.703	94	0.786	97	0.98	1.00
Thailand	EAP	Upper Middle	Tropical	0.624	49	0.817	50	0.847	65	1.83	1.82
Togo	SSA	Low	Tropical	−0.297	150	−0.008	150	0.476	144	0.06	0.32
Trinidad And Tobago	LAC	High	Tropical	0.443	102	0.525	128	0.480	143		
Tunisia	MENA	Lower Middle	Temperate	0.746	17	0.911	14	0.933	20	3.47	4.06
Turkey	ECA	Upper Middle	Temperate	0.573	63	0.721	90	0.772	104	3.85	4.27
Turkmenistan	ECA	Upper Middle	Tropical	0.889	3	0.955	4	0.957	8	4.12	4.30
Uganda	SSA	Low	Tropical	0.201	128	0.553	126	0.824	83	0.00	0.01
Ukraine	ECA	Lower Middle	Continental	0.488	89	0.748	78	0.840	71	2.85	3.25
United Arab Emirates	MENA	High	Arid/Desert	0.662	39	0.844	41	0.882	48	5.00	5.00
United Kingdom	ECA	High	Temperate	0.551	67	0.803	57	0.865	57	2.57	2.38
United States	North America	High	Temperate	0.608	54	0.809	54	0.862	58	3.17	3.32
Uruguay	LAC	High	Temperate	0.497	83	0.753	76	0.810	91	0.68	0.59
Uzbekistan	ECA	Lower Middle	Arid/Desert	0.766	14	0.904	15	0.920	26	4.03	4.19
Venezuela	LAC	Upper Middle	Tropical	−0.006	137	0.510	129	0.687	125	1.92	1.98
Vietnam	EAP	Lower Middle	Tropical	0.676	35	0.798	58	0.849	63	1.04	0.96
Yemen	MENA	Low	Arid/Desert	0.574	62	0.893	19	0.929	21	4.95	4.74
Zambia	SSA	Lower Middle	Tropical	0.454	94	0.726	87	0.785	98	0.00	0.20
Zimbabwe	SSA	Lower Middle	Tropical	−0.543	152	0.359	142	0.653	129	0.68	1.02

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