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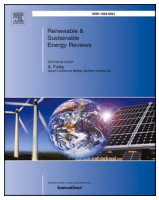

The unspoken value of water infrastructure

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ABSTRACT

Water infrastructure forms the backbone of development, being pivotal for water, food and energy security. Both existing and new infrastructure must cope with global climatic challenges and increased human activity. Continuous investment in water infrastructure is crucial, yet in many cases, investments are deferred as they are not perceived as a priority, leading to deterioration, and public attention typically only arises after accidents or malfunctions occur. A prevailing lack of social awareness, combined with the mismatch between infrastructure lifespan and political cycles, further limits political will—especially regarding investment in ageing systems. This article was prepared to accentuate the extraordinary value provided by water infrastructure. Examples of recent global events are used to exhibit the profound benefits that rarely make their way into traditional cost-benefit analyses to inform decision making. These examples also showcase how essential sustainable development activities (SDG 6, 7, 9) would be severely compromised in their absence. This perspective also contributes to the ongoing debate about water infrastructure not being "fit for finance", arguing that current financing and investment frameworks –as well as public perception– fail to capture the true societal and macroeconomic value of such systems, thus reinforcing their importance amidst changing climatic and human pressures.

1. Water infrastructure: From funding to *true* value

Perhaps because of its success, water infrastructure is taken for granted with their original purpose often remaining overlooked. It has served as support for development for millennia with deceivingly low effort, typically operating unnoticed –almost hidden in plain sight. Water infrastructure does not only serve for drinking water and wastewater services, but also irrigation, energy generation (water-food-energy nexus), flood and drought protection and enabling navigation across key transportation pathways. Depending on their physical scale, infrastructure can cut across large geographies or even modify transboundary river basins; but at the same time is represented by the intricate networks of smaller plumbing services integrated into local communities and households, often remaining hidden from sight. From planning and design, and involving enormous collaborative efforts through construction and commissioning, these feats of modern-day civil engineering now function silently as societal systems continue about day to day business.

Water infrastructure, particularly large-scale projects, create a large degree of irreversibility, as it shapes surrounding socio-economic systems: people establish settlements protected by flood barriers, irrigation systems flourish due to a dam's large and stable storage, and global supply chains are redefined by waterways and canals. Because of this enduring legacy, a failure can have catastrophic consequences, which is why complacency has led us into difficult situations in the past. At times, certain assets –frequently dams or other large infrastructure projects– come to public attention when something goes drastically wrong, serving as an abrupt reminder of the intrinsic threat that they can pose to

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the environment [1–4], in transboundary conflicts and wars [5–7] and the negative implications that old infrastructure has had on safety and sustainability [8–13]. Although these impacts must be taken seriously, it appears that for most infrastructure, the value that it can provide to society does not win over their apparent risks in the eyes of the public.

The complexity of infrastructure projects introduces numerous challenges –not only for its management and governance– but also in securing funding across their entire life cycle. These projects typically involve complex planning and financing of large, often unique structures across extraordinarily long timescales, very frequently beyond political cycles and occasionally exceeding human lifespans of those who witnessed the benefits coming from these projects. Funding can come through private investors, benefiting communities or non-governmental organisations. Contributions can also come from local and national governments, public-private partnerships, user tariffs, multilateral development finance institutions or foreign direct investment seeking a profitable return, among others. Each funding mechanism has its own unique characteristics and implications [14–16], which further influences the feasibility, sustainability and long-term outcomes of these projects.

Despite all these options, the World Water Council and the Organisation for Economic Cooperation and Development determined that water infrastructure is not "fit for finance" [17]. Concomitantly, the American Society of Civil Engineers, for instance, has reported that the overall state of infrastructure in the United States was at a low grade C in 2021 (i.e., *mediocre*, although better than prior assessments), where an associated funding gap of 2.59 trillion USD over a decade (2020–2029) was identified [18]. In 2018, the European Parliament [16] recognised the European Investment Bank's funding gap figure of €688 billion per year required in investment needs for energy, transport, telecoms and water and sanitation. This was potentially accentuated by the response to the economic and financial crisis of 2007. This value of course would fall significantly short when considering the needs for funding new infrastructure to meet climate targets. Globally, the funding gap to meet SDGs by 2030 can be as large as 2.5 trillion USD per year [19].

To address this challenge, we need to consider new ways to value water infrastructure or to make investment attractive to a new generation of stakeholders to close the funding gap. In doing so, we should not overlook the unspoken benefits of water infrastructure, which is often not suited to traditional cost-benefit analysis or private investment return goals, but may play a deeper role in long-term, macroeconomic investment decisions if understood properly. This communication was therefore prepared to help highlight the imminent and long-term multifaceted contributions that water infrastructure can provide. Selected examples of infrastructure are presented in the next sections demonstrating their value.

2. Commercial transportation

One morning in late March 2021, the world woke to a container vessel blocking the Suez Canal in Egypt (Fig. 1). By putting the global trade on hold, it reminded us of the role of this 152 year-old waterway. The blockage alone led to an estimated economic loss of 6–10 billion USD per day in the global economy [20]. A mere three summers prior to the Suez Canal incident, the heavily industrialised and tightly regulated Rhine River –a key artery for the transport of European products– suffered dangerously low water levels, which severely impeded the transport of fluvial vessels. This incident alone led to a 0.7% reduction in Germany's economic growth [21]. Despite extensive engineering and meticulous planning effort, droughts serve as a stark reminder of the indispensable role of this waterway. Regrettably, in the summer of 2024 the Rhine endured low water levels [22], once again reminding to the public of the dependence of our economy has on water infrastructure.

3. Large dam reservoirs for water-food-energy security

Far beyond economics, water infrastructure has a vital role in societal development. For instance, large dam reservoirs can store fresh water for months, or even years, ensuring on-demand access whilst also supplementing water resources during periods when water is scarce. With the increasing height of a dam, the reservoir volume grows monotonically or even exponentially. Therefore, for every few additional meters, its storage capacity can be significantly increased. This intrinsic feature enhances the utility of large dams over many smaller dams. The latter, although smaller, can also have similar environmental impacts provided that most dams are barriers to the water courses [23]. However, large dams can play a multifaceted role in society, very often simultaneously tackling multiple purposes at once. These reservoirs, in combination with groundwater storage, are essential for sustaining agriculture and hence food security [24,25], especially since irrigation is one of the most water-intensive activities. Without dam reservoirs, food security would be seriously compromised [26].

The value that dam reservoirs provide may well be forgotten by water, energy and food consumers after a few years of operation. A recent, potent reminder of their presence surfaced amidst the ongoing conflict in Eastern Europe (Fig. 2). Prior to the incident, experts and media alike sounded the alarm about the significant risks associated with the potential destruction of the Kakhovka dam [6,27,28]. Despite its comparatively modest hydropower generation capacity (357 MW), its recent destruction has unveiled its critical role in the region, rendering 94% of irrigation systems in Kherson, 74% in Zaporizhzhia and 30% in Dnipro water-deprived [6]. Furthermore, the Zaporizhzhia nuclear power plant (5.7 GW) and the Crimean peninsula had their water supply

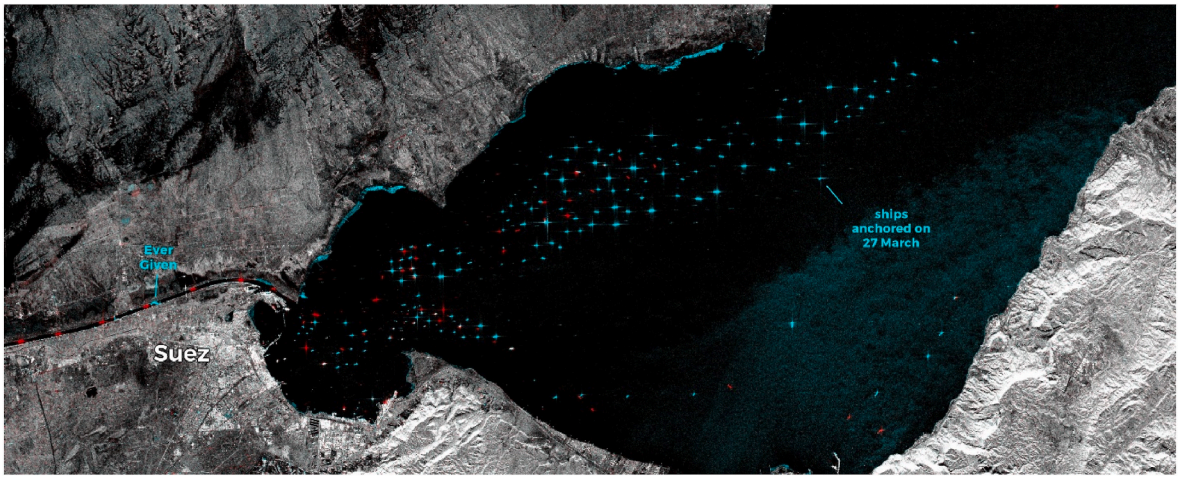

Fig. 1. Suez Canal blockage by the Ever Given vessel. Credit: European Union, Copernicus Sentinel-1 satellite (combined images of 21 and 27 March 2021).

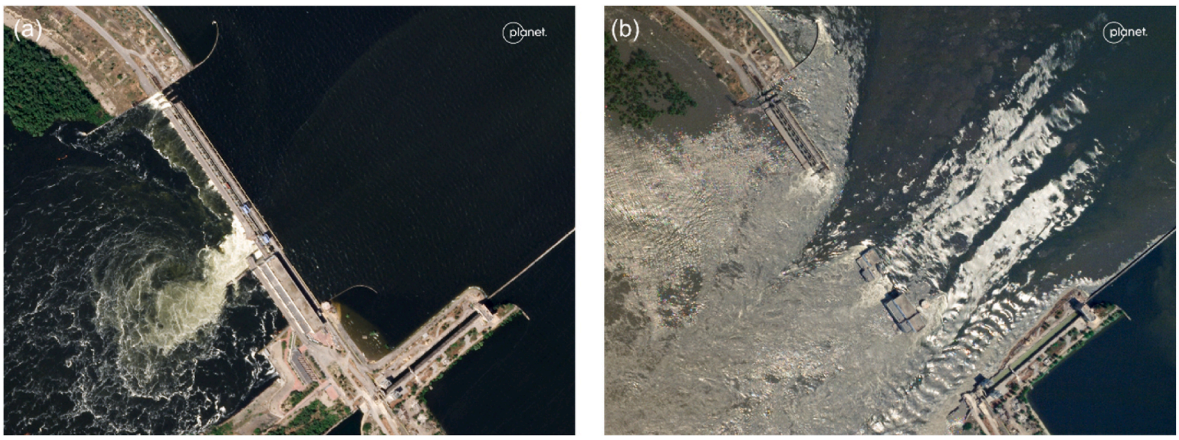

Fig. 2. Satellite images of Kakhovka hydropower dam (images' credit: Planet) on: a) June 4, 2023 and b) June 6, 2023.

also compromised due to this incident. Under normal circumstances, very few people would have realised the significant contribution that this medium-sized hydropower plant had for irrigation, large scale energy generation and food and water security in the region.

In the global context of energy generation and storage, the narrative is unquestionable. In 2021, hydropower provided 16% of global electricity (40% of renewables' generation capacity [29]). It is also estimated that its potential capacity is approximately four times its current installed capacity [30]. Countries leveraging hydropower benefit from reduced reliance on foreign policies and volatile energy prices. Furthermore, according to the World Bank estimations [31], multipurpose dam projects yield up to one additional dollar, for every dollar invested, through indirect economic effects at a regional and interregional scale. Taking the full lifetime cost into account, electricity produced by hydropower has traditionally remained one of the lowest cost, low-carbon renewable technologies over many decades [32]. However, a recent study [33] indicated that reservoir dams contribute significantly more methane emissions than previously anticipated. This highlights the importance of strategic planning, such as reducing organic mass in reservoirs before their initial filling to reduce these emissions.

Currently, hydropower constitutes 95% of the world's electricity storage capacity [34] and, with the ever decreasing costs for solar and wind intermittent energy [35], the role that reservoirs play in providing reliable, versatile and fast-response energy may prove to be pivotal in the energy transition. This is particularly true for meeting peak demands while simultaneously fulfilling multiple purposes such as irrigation, water supply and flood control, which is the case for about half of the large dams, according to the International Commission On Large Dams [36]. This is a unique aspect of this type of water infrastructure, as compared to any other civil infrastructure or energy systems; unfortunately, this characteristic can also further complicate financing when competing interests and priorities arise [17].

4. Sanitation, emerging contaminants and epidemics

Another crucial function of water infrastructure is to ensure safe access to drinking water and sanitation. Despite the alarming statistic that one in three people still lack access to safe drinking water nowadays [37] where untreated water is responsible for 1.2 million deaths each year [38], sanitation is taken for granted in most high-income countries. This has not always been the case; between 1831 and 1854, London faced three large epidemics of cholera with nearly 20,000 deaths in the latter event alone [39]. It was against this backdrop that Sir Joseph Bazalgette masterminded the construction of the 2220 km long London sewage system, aimed primarily at eliminating such a catastrophic health crisis and mitigating the risk of another incident akin to the infamous 1858 "Great Stink".

Water infrastructure also plays a key role in dealing with emerging contaminants such as personal care products, endocrine disrupting compounds, pharmaceuticals and their transformation products that are of increasing concern for human health and the aquatic ecosystem [40]. Next to the need for investment to make sewage systems and water treatment infrastructure suitable for their removal [41], dam reservoirs and related sedimentation processes have been consistently identified as major sinks of emerging contaminants within river networks. Studies have found a wide range of contaminants (microplastics, pharmaceuticals, pesticides, sterols) in reservoir sediments [42,43].

5. Flood protection

Water infrastructure also plays a key role in keeping society safe from floods, one of the deadliest extreme weather manifestations [44]. The ongoing safety level provided by these structures over the course of days, months or years, may not be appreciated by the public primarily because of their successful operation. Flood defence infrastructure are frequently built to serve as a protecting measure against infrequent events; in other words: low probability events, but with fatal consequences. Flood risk perception decreases seven years following a catastrophe [45,46] and, as society is continuously spared from these devastating impacts, this lack of renewed awareness tends to discontinue political engagement, since timescales of elections are considerably short-termed. Although the benefits of flood protection are undeniable, for existing infrastructure, maintenance and upgrading might not always methodically fit into a cost-benefit analysis or align with investment return targets. This is especially important from a social equity perspective considering that exposure is often uneven [47].

The fact that many destructive events do not occur in a person's lifetime, and that many disasters are already prevented by existing water infrastructure [44], diffuses the perceived value of water infrastructure to society [46,48]; which is nonetheless expected to become even more important under the threat of climate change [49]. Negative effects, however, can be perceived daily and dominate the literature [50], leading to an unbalanced view, which does not often align with the role water infrastructure had in development –frequently acknowledged by experts [19,51–53].

In the past, it has been through tragic events that major infrastructure for flood protection has been promoted. For instance, a tragic storm hit the shores of the Netherlands in 1953 and took the lives of over two thousand people. After this event, the Dutch felt the risk as never before, and as never again until today. Awareness was abruptly triggered –both in the Netherlands and across borders– and the damage done to flooded areas along with the significant loss of human life remained fresh memory for a while. That day, the Dutch received a striking reminder of the powerful forces of nature, which was then transformed into an action

to develop what was technically thought to be impossible at the time. Many of those now walking over the thousands of kilometres of Dutch dikes may neither know nor remember their purpose. When citizens perception is biased, increasing investments in monitoring, maintenance or upgrading of this important water infrastructure can become politically undesirable, which poses yet an additional challenge on safety officials and may contribute to gradually increasing risks.

Another recent reminder of the critical role of flood protection occurred during the severe floods in East Spain in October 2024, predominantly impacting the southern areas of Valencia, resulting in over two hundred casualties. Valencia experienced a similar event in 1957, which prompted the development of an ambitious flood infrastructure plan. This, together with the flood attenuation effect of the Forata dam's reservoir [54], saved many lives during this new event. However, for many decades, this infrastructure was remarked on by the public as representing a waste of resources, given that the flood release channels remained dry for most of the year. This lack of public awareness or consideration hindered further investment in both ambitious structural and much-needed non-structural flood mitigation measures. Despite views on the usefulness of the infrastructure, society should prepare for more. Preliminary analysis suggests that this rainfall was 12% more intense and twice as likely due to climate change [55], and is compounded with the increased human exposure commonly occurring after protecting flood-prone areas.

6. Conclusions

Wake-up calls, such as the recent deadly floods in Valencia or the dam breaks of Libya –amounting to several thousands of fatalities [56]– could be rare yet decissive catalysts for policymakers to reflect and propose ambitious programmes to upgrade and future-proof existing assets. Ageing infrastructure, while continuing to provide an important service to society, may not rank high in investment priority decisions while needing new types of efforts, involving maintenance and upgrading without usually appearing to add a new value to the existing one.

Securing investments may continue to be a major challenge, especially because the true value of infrastructure does not align with traditional cost-benefit analyses and the actors most benefitting may not have the financial nor organisational capacity required. Social equity and a good fit into a more integral long-term strategy should always be observed, beyond government life-cycles. Additionally, new approaches to promoting infrastructure should also consider the intangible benefits and *unspoken* value that plays a deeper role in delivering long-term, macro-societal and macro-economic impacts to make investment attractive to next generation stakeholders' –comprising a mixture of public and private led institutions– in order to close this ever-widening funding gap.

Public awareness generated from catastrophic events is short-lived [45,46]. Drawing from attitudes around *fake news*, "*people are most likely to share material online that angers them*" [57], and a large part of the public will soon again focus only on the recurrent negative aspects of infrastructure; and, just as with disinformation [58], it will not contribute to having a more balanced perspective needed to take important decisions. Future catastrophic events, whether be pollution, floods, dam failures or transportation issues, should be used as a push by relevant stakeholders, fast and bluntly. Along with renewed awareness generation, public administrations and policy makers need to show a stronger will than before. This is necessary to ensure that infrastructure remains a reliable and resilient backbone to society.

Credit author statement

DV led the original writing and editing, with contributions from EP and VH. MK, DB, SM and SE contributed to the discussion and assisted with writing and revisions.

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 article.

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Data availability

No data was used for the research described in the article.

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