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Global applicability of solar desalination

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A B S T R A C T

Over-exploited fresh water resources, fossil-fuel depletion and climate change all highlight need for desalination powered by renewable energy. This study briefly reviews literature on solar desalination technologies and examines economic and environmental feasibility. The maturest technology appears to be reverse osmosis driven by photovoltaics. Many studies refer to apparent spatial coincidences of water scarcity, solar energy abundance and saline water availability, but none examine the phenomenon objectively from a global perspective. This study proposes a method for correlating international data on water scarcity and stress, saline water resources, and insolation levels, to calculate rank scores ($0 \leq R \leq 1$) which identify where solar desalination is most applicable. Low scores ($R < 0.125$) occur in landlocked nations with limited saline groundwater resources (Nepal, Bolivia, South Sudan) and near polar regions where fresh water is abundant and solar insolation levels are low (Canada, Russia and Scandinavia). High scores ($R > 0.422$) occur in 30 nations, including Middle Eastern and North African countries where fossil fuelled desalination is commonplace, and solar desalination has obvious applicability. The analysis identifies 28 further countries (including parts of USA, China, India, Indonesia, Australia, and countries throughout Africa, Asia, South America and Europe) where $0.273 < R < 0.422$ scores indicate that other, less obvious, solar desalination opportunities exist.

1. Introduction

Solar desalination has obvious applicability in arid regions where fresh water scarcity, solar resource abundance and saline water availability are observed to coincide. This observation seems most commonly referred to in the Middle Eastern and North African context [1–13], but also in relation to other parts of the world including China [14,15], rural regions of India [16,17], and southern Europe [18]. There do not appear to be any studies which objectively examine solar desalination applicability from a global perspective, which is the main aim of this study.

The first part of this study reviews the key issues concerning the sustainability and interdependency of our water and energy resources. International data on water scarcity and stress is then presented and the growing need for desalination plants powered by renewable energy is established. A brief review of solar desalination technology types is presented and the global availability of saline water and solar energy resources is examined. The main factors affecting solar desalination plant feasibility are briefly reviewed, including technology maturity, economics and environmental impact. Cartographic data on water scarcity and stress, insolation levels, and saline water resources are then used to identify and rank countries where deployment of solar desalination technologies might be targeted. The results could help inform national and international water management policies and assist suppliers in identifying and quantifying emerging markets for solar desalination plant.

2. The water-energy nexus

Human beings need fresh water, food and shelter to survive. Production of food stuffs and construction materials requires both fresh water and energy resources. The United Nations World Water Development Report 2014 [19] focused on these interdependencies (commonly referred to as the "Water-Energy Nexus") and highlighted that "*…water use and management and the production of energy can have significant, multifaceted and broad-reaching impacts on each other… drought exacerbates energy crises; energy price volatility contributes to food crises; the expansion of irrigation networks increases water and energy demand; and access to*

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unreasonably inexpensive supplies of energy can lead to the depletion of water resources, further intensifying the impacts of droughts." A breakdown of global freshwater use is presented in Fig. 1. Normal consumption of drinking water is 2–4 L/day for adults and 0.75 L/day for infants [20]. Domestic water consumption for washing and cooking varies significantly in different countries, typically between 50 and 500 L/day [21]. By contrast, agricultural demands for fresh water (primarily for irrigation) are vast. Agricultural water demands are particularly high for arable farming in hot climates and for high value products such as grain fed cattle. Global energy supplies including fossil fuel production (extraction and refining processes), biofuels production (irrigation and processing), thermal electricity generation (steam and cooling water) and hydroelectric power (evaporative losses) are also major consumers of water [22]. Paradoxically, water supplies account for a significant share of global energy consumption (see Fig. 2). This energy is mainly required for pumping water from bores and through pipelines, for sewerage treatment and desalination.

Annual abstractions of fresh water from the world's lakes, rivers and ground aquifers amount to ~4000 km^3/year [24]. Considering the differences in national water footprints of developed and developing countries [25] fresh water demand could conceivably double or perhaps even quadruple by 2050 owing to population growth and improving living standards. Current global energy consumption is ~350 EJ/year and a 20–50% increase is expected by 2050 depending on how efficiently we use energy in the future [21,23]. Fig. 2 shows that water extraction, treatment and distribution accounts for 8% of global energy consumption. Average energy intensity of global water supplies can therefore be estimated as ~7 MJ/m^3 (calculated by taking 8% of 350 EJ/year and dividing by 4000 km^3/year). Energy intensities of various common water supply scenarios is given in Table 1. Increasing urbanisation, growing populations in water scarce areas, and climate change will limit the possibilities of reliance upon low energy intensity water supply methods. Significant demand reduction is likely to be achievable by employing more efficient agricultural irrigation techniques and reducing wastage caused by leaks, but increased reliance on waste water reuse, long pipelines, and desalination, seems inevitable. Water supply system energy intensity will increase correspondingly.

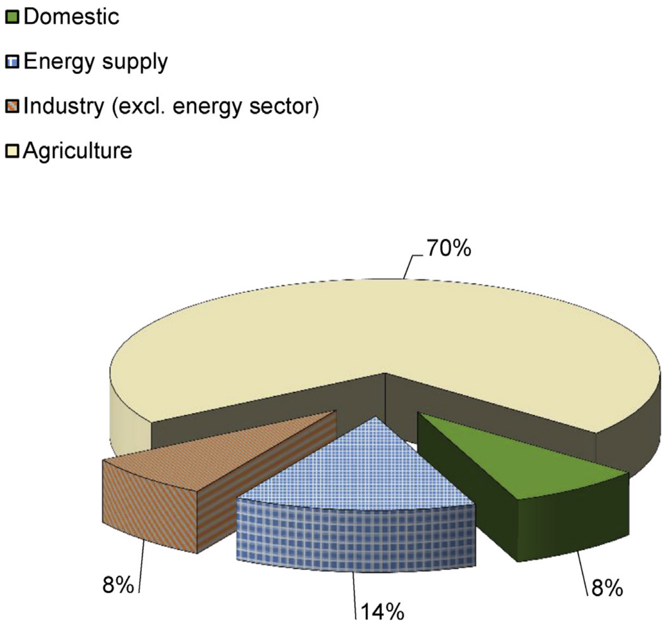

Fig. 1. - *Global use of fresh water*. Based on data from UN-Water [21].

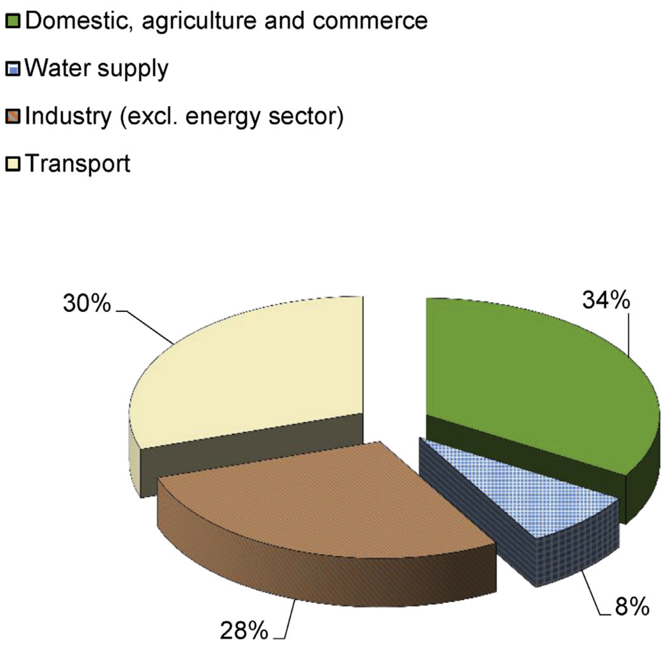

Fig. 2. - *Global use of energy*. Based on data from UN-Water [21] and IEA [23].

3. Water scarcity and stress

Definitions of the terms "water stress" and "water scarcity" vary in the literature and the terms are often used interchangeably.

If a region is experiencing "water stress" this usually means that fresh water abstractions are occurring at rates higher than natural recharge rates. Consequent reductions in lake and river water levels have obvious visual impacts and can have catastrophic consequences for supported ecosystems, both aquatic and terrestrial. There may also be adverse social impacts associated with fishing and water navigation. Depletion of groundwater aquifers is much less visible but can have equally dire consequences [33] including: reduced flow of natural springs with consequent effects on downstream rivers and lakes; increased groundwater salinity owing to ingress of seawater into fresh water aquifers; and lowering of the water table which increases depths of wells and bores with consequent increases in energy required for pumping. Water resource depletion is usually temporary in the sense that recovery occurs when abstractions cease. Ecosystem destruction and increased ground water salinity may however be long term or permanent consequences. Certain types of aquifers (such as the Connate aquifers found deep under the Sahara desert) are no longer actively recharged so their depletion would be essentially permanent [34].

The concept of "water scarcity" usually relates to per capita availability of fresh water resources. Scarcity can be caused by a genuine lack of water – "physical scarcity" or by a lack of water infrastructure – "economic scarcity", or a combination of both. Stress can be defined as a ratio of quantity abstracted divided by quantity of renewable water available. Degrees of water scarcity and stress are defined in Table 2.

Table 3 lists some of the factors which typically cause water stress and physical scarcity [35]. Fig. 3 shows a map quantifying global renewable water resources, colour coded to indicate countries where there is physical water scarcity on an overall per capita