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Review

The Water-Energy-Food Nexus: Climate Risks and Opportunities in Southern Africa

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Abstract: The discourse on the need for water, energy, and food security has dominated the development agenda of southern African countries, centred on improving livelihoods, building resilience, and regional integration. About 60% of the population in the Southern African Development Community (SADC) live in rural areas relying mainly on rainfed agriculture, lacking access to clean water and energy, yet the region is endowed with vast natural resources. The water-energy-food (WEF) nexus is a conceptual framework that presents opportunities for greater resource coordination, management, and policy convergence across sectors. This is particularly relevant in the SADC region as resources are transboundary and supports efforts linked to regional integration and inclusive socio-economic development and security. We conducted an appraisal of WEF-related policies and institutions in SADC and identified linkages among them. The present 'silo' approach in resource management and allocation, often conducted at the national level, contributes to the region's failure to meet its development targets, exacerbating its vulnerabilities. The lack of coordination of WEF nexus synergies and trade-offs in planning often threatens the sustainability of development initiatives. We highlighted the importance of the WEF nexus to sustainably address the sectoral coordination of resources through harmonised institutions and policies, as well as setting targets and indicators to direct and monitor nexus developments. We illustrate the significance of the nexus in promoting inclusive development and transforming vulnerable communities into resilient societies. The study recommends a set of integrated assessment models to monitor and evaluate the implementation of WEF nexus targets. Going forward, we propose the adoption of a regional WEF nexus framework.

Keywords: resilience; SDGs; climate change; livelihoods; water-energy-food nexus; SADC

1. Introduction

Water, energy, and food are vital for human wellbeing, poverty reduction, and sustainable development. The three resources are strongly linked as food production needs water and energy; water management (extraction, treatment, and redistribution) requires energy; and hydro-energy production (major source of energy in southern Africa) requires water [1–4]. Any impact on one affects the other two. These interconnections are described as the water-energy-food (WEF) nexus [3,5],

which, when well implemented, leads to socio-economic securities and development [3]. Formal published evidence of the three-way mutual interactions among the WEF nexus components only started in 2008 [6], and has since emerged as an important concept for integrated resource management at various spatial scales [7]. Due to the current and forecasted increase in global demand and pressure on the WEF resources, and the strong linkages between the WEF sectors and sustainable development, the WEF nexus is increasingly being recognised as an approach to effectively manage sustainable development [3,8,9]. The WEF nexus is, thus, a framework that captures the inter-relations, synergies and trade-offs between the demand on water, energy, and food in the context of threats, and emerging constraints of sustainable development in particular regions or systems [7,10]. WEF nexus thinking is a method based on a systems approach, for example, using the socio-ecological system as the primary point of reference, and is gaining recognition within the scientific community and among policy makers [4,11]. It has grown to be an essential approach to achieve the Sustainable Development Goals (SDGs) on poverty alleviation, zero hunger, provision of water and sanitation, and access to affordable and reliable energy (Goals 1, 2, 6, and 7, respectively) [4].

Despite the recognition of WEF nexus linkages, current approaches are such that management of the three sectors often falls under sector specific institutions, with sector driven mandates. This has been partly attributed to a policy environment that does not recognise cross-sectoral linkages and the general 'silo' approach to resource management, particularly in southern Africa [3,12,13]. Sectoral policies and institutions are designed to operate in silos; this creates an imbalance and often duplication in resource allocation, which translates to failure to deliver and in inefficiencies in resource use, negatively impacting on sustainable development [3]. Although the Integrated Water Resources Management (IWRM) concept embraces other resources, it is generally water centric, whereas the WEF nexus considers all resources in equal terms as they are interlinked, depending on each other. Thus, the WEF nexus is multi-centric.

In the case of southern Africa, where the region as a whole faces water, energy, and food insecurities, a WEF nexus approach could unlock positive synergies needed to catalyse regional development. This could be achieved through, for example, coordination among countries in joint investments in energy projects in one country and sharing the resource, while ensuring that the water saved by the other countries is freely released for agriculture purposes in other Member States. For example, South Africa is considering harnessing water from the Democratic Republic of Congo (DRC) in exchange for energy. This forms part of South Africa's National Water Sector Plan currently being championed by the National Planning Commission (NPC). The region also faces increasing demand for water, energy, and food due to population growth, urbanisation, and economic development [14], thus necessitating greater coordination of the WEF sectors to meet current and projected demands. The region has significant shared water (surface and groundwater) and energy resources and infrastructure [15]. In addition, several sector specific regional institutions tasked with coordinating these regionally shared resources and infrastructure already exist and could provide a useful platform for embedding the WEF nexus [3,4].

The fifteen transboundary river basins within the SADC region provide an opportunity for riparian countries to achieve short and long-term benefits through an integrated and coordinated operation of existing and planned hydropower facilities, cooperative flood management, and irrigation development [3]. Cooperation among riparian countries in the Zambezi Basin has the potential to create a reasonable balance between hydropower and irrigation investment that could result in the stable energy generation of 30,000 Gigawatt hours (GWh)/year and 774,000 ha of irrigated land [16]. Most large dams in the region remain underutilised as they were originally designed for single purposes. However, some, like the Itezhi-Tezhi Dam in Zambia, are being redesigned for multipurpose activities, such as hydropower and irrigation [17]. The Kariba Dam was also originally commissioned only for hydropower generation, but it is now used for aquaculture, urban water supply, eco-tourism, transport, and mining activities [18]. This highlights opportunities for WEF nexus pilot projects within the region that could be replicated elsewhere.

The recognition of the role that can be played by the WEF nexus in regional socio-economic security, cooperation, and integration, was highlighted by the WEF Nexus Action Plan, which forms part of the Regional Strategic Action Plan IV (RSAP IV) [19]. The action plan recognises the role of the nexus in adapting to the challenges posed by population growth and climate variability and change, as well as in optimising resource use to achieve regional goals and targets. Despite the presence of the WEF nexus action plan, there is little or no evidence of cross-sectoral linkages between institutions, policies, and current projects. This highlights a challenge in implementing the WEF nexus approach and can be attributed to a lack of guiding frameworks for its implementation. There is also not much clarity on the spatial scale at which implementation should occur and how to quantify or assess such implementation. This further alludes to the need for WEF nexus indicators and metrics, which, when coupled to the frameworks, could allow for implementation.

The pressure to produce more food and energy under increasing water scarcity requires the WEF nexus to balance competing demands for water resources. While current developmental approaches have often negatively impacted on other sectors and sustainability thereof, a WEF nexus approach could contribute to sustainable socio-economic and inclusive development [5,12,14]. Climate change projections which indicate increased pressure on water, energy, and food resources, further justify the need for a coordinated and integrated approach to sustainable development [20,21] such as the WEF nexus approach. The resource rich transboundary river basins of the SADC region present opportunities to cement regional integration, promote inclusive sustainable development, and ensure socio-economic security.

This study thus explores opportunities for the WEF nexus in promoting cross-sectoral policy linkages among water, energy, and food sectors at a regional level to achieve regional integration and sustainable development. The study provides an appraisal of the region's WEF resource endowment, climate change impacts, and policy and institutional arrangements. We further propose a regional nexus framework for implementing the WEF nexus, as well as possible tools for monitoring and evaluating WEF nexus implementation. Thus, the study recommends an integrated model and tools for WEF nexus implementation at a regional level to promote integrated regional development, ensure socio-economic and political security, and achieve regional integration.

2. Materials and Methods

2.1. The Study Area: SADC Region

The SADC region (Figure 1) is a regional economic community of southern Africa countries. It has a combined area of 986,246,000 ha, of which only 6.11% is cultivated [22]. Agriculture is mainly rainfed, sustaining the livelihoods of over 60% of the population. Land with irrigation potential is approximately 20 million ha, of which only 3.9 million ha is equipped for irrigation, accounting for about 6.6% of cultivated area [22]. These factors, coupled with the underutilisation of arable land where only 21% of the region's 225.6 million ha of arable land is under cultivation and 3.5% under irrigation [22], exacerbate the vulnerability of the region to food insecurity.

The region is endowed with vast but unexploited energy resources. The resource rich 15 transboundary river basins of the region (Figure 1) present opportunities for regional integration and coordinated and sustained growth through the WEF nexus. However, extreme weather events of drought and flooding that characterise the region exacerbate regional vulnerabilities. An example is the 2015/16 drought, which caused over 40 million people to be food insecure, as dam water levels were reduced, causing intermittent power outages in most countries in the region [23]. Seventy five percent of the SADC region is arid or semi-arid, and the climate varies from desert, through temperate, savannah, and equatorial, receiving rainfall of between 650 mm in the driest areas and 2000 mm in the wettest regions.

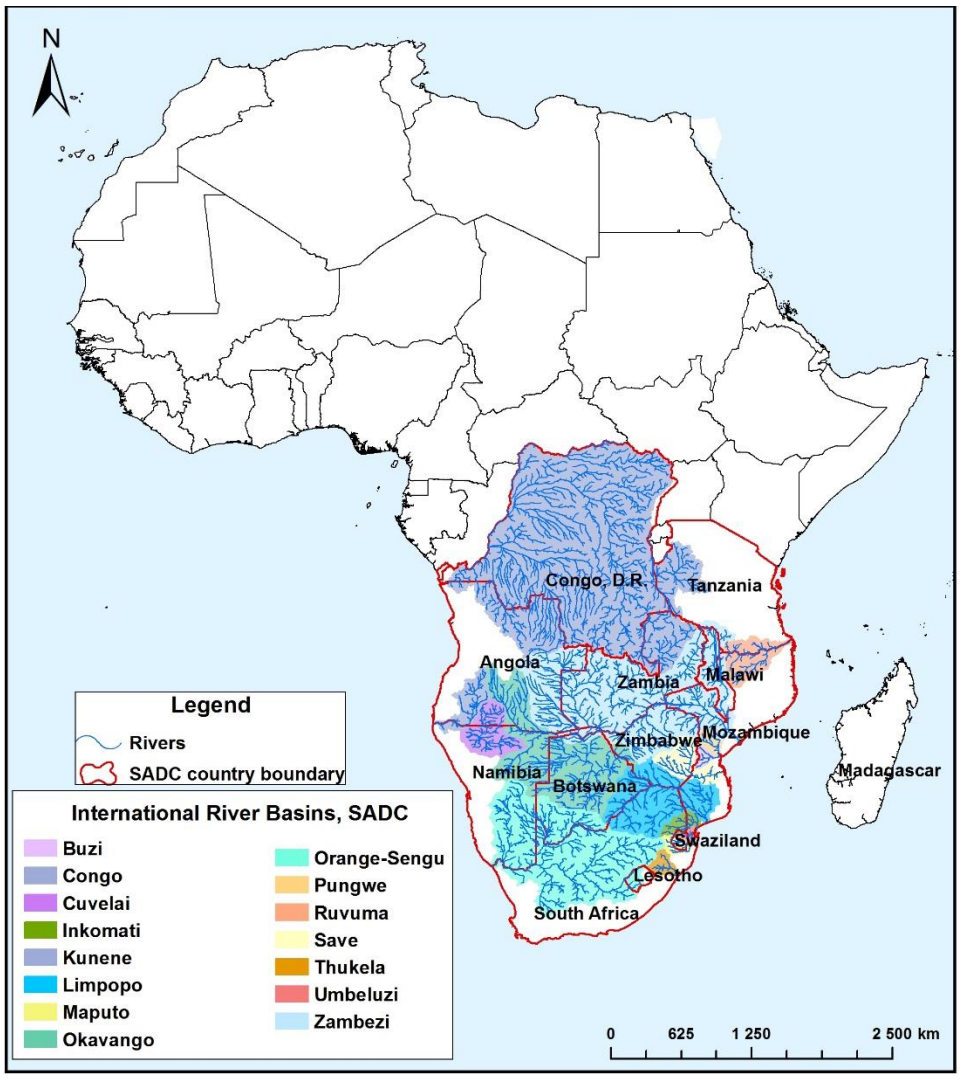

Figure 1. Location of SADC countries and their transboundary river basins. Source: Developed by authors.

2.2. Regional WEF Nexus Conceptual and Methodological Model

Figure 2 is an illustration of the conceptual and methodological model used to assess SADC regional WEF nexus; its policies, institutions, and constraints, with an aim to develop a regional nexus framework. The model explores the interactions between human and natural systems that maximise Human-Environmental Security (risk reduction) through the nexus. It emphasises a shared biophysical and socio-economic resource base of the SADC region, to achieve regional water, energy, and agriculture developmental targets. An assessment of water, energy, and food availability in the region is done to identify opportunities for integrated resource management through the WEF nexus. Agriculture is used as a proxy of the food component of the nexus. A literature review of the current regional policies and institutions is conducted to measure their interconnections and gauge their role in promoting regional integration and socio-economic security. An overview of rainfall variability and climate change is made to understand how they have impacted on water, energy, and food resources. The study then recommends an integrated model for assessing and monitoring WEF targets and indicators. A procedural regional flow-chart in the form of a framework is developed to guide the nexus implementation.

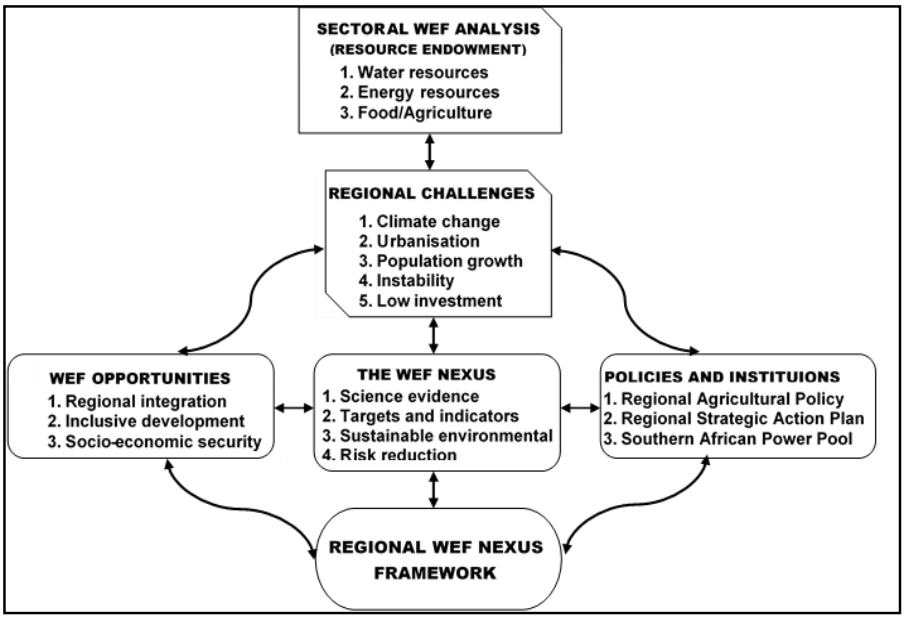

Figure 2. A regional WEF nexus conceptual and methodological framework. Source: Developed by authors.

3. WEF Resources Endowment in the SADC Region

3.1. Water Resources and Availability

Seventy five percent of the SADC region, mostly the southern part, is arid to semi-arid with a Climate Moisture Index (CMI) of less than −0.6, receiving less than 650 mm of rainfall per annum [24]. The rest, 25%, which is mostly occupied by northern countries that are closer to the Equator, is classified as sub-humid with a CMI of 0.25, receiving between 651 and 2000 mm of rainfall per annum [24]. The highly variable rainfall that oscillates between 100 and 2000 mm per annum is indicative of the uneven distribution of rainfall and water availability across the region [25]. In addition, 75% of the region is classified as water scarce, mainly due to the uneven distribution of water resources. The mean annual runoff volume of 650 km^3 is substantially low for a region that depends on agriculture and hydro-power [26]. Some countries like the DRC, Mozambique, and Zambia have water resources capable of generating enough hydro-power for the whole region, whereas some countries in the south are water scarce, always experiencing power blackouts. Thus, management of water resources at the basin level would benefit from integrated development. Total renewable freshwater resources are estimated at 2300 km^3 per annum, of which 70% of water withdrawals is used in agriculture, 20% for domestic use, and 10% for industrial use [27,28]. Although agriculture uses the bulk of the freshwater resources, crop production remains very low, failing to meet the food requirements of a growing population [29]. These factors contribute to the region's water insecurity. Water security is the capacity of a country to ensure sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, to ensure protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability [11].

Seventy percent of surface water resources are in 15 transboundary river basins (Figure 1 and Table 1). The transboundary nature of the river basins signifies the importance of watercourses in promoting regional integration and development. For example, five SADC countries have water resource dependency ratios of over 50%, that is, they rely on water generated outside their borders to supply more than half of their total water requirements [29,30]. Although groundwater abstraction has increased in recent years, little is known about the aquifers, most of which are also transboundary in nature [31]. As already alluded, the shared natural resources form the basis for the development of

regional instruments that support joint management for inclusive development and cement regional cooperation and integration.

Table 1. SADC transboundary river basins (IRBs) and the riparian states.

River Basin	Riparian States
Buzi	Mozambique, Zimbabwe.
Congo	Angola, Democratic Republic of Congo, Tanzania, Zambia
Cuvelai	Angola, Namibia
Incomati	Mozambique, South Africa, Swaziland
Kunene	Angola, Namibia
Limpopo	Botswana, Mozambique, South Africa, Zimbabwe
Maputo	Mozambique, South Africa, Swaziland
Nile	Democratic Republic of Congo, Tanzania
Okavango	Angola, Botswana, Namibia
Orange	Botswana, Lesotho, Namibia, South Africa
Pungwe	Mozambique, Zimbabwe
Ruvuma	Malawi, Mozambique, Tanzania
Save	Mozambique, Zimbabwe
Umbeluzi	Mozambique, Swaziland
Zambezi	Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe

3.2. Energy Resources and Potential

While individual countries vary in their resources availability, the SADC region as a whole is endowed with vast energy resources. For example, the untapped potential of hydropower generation in Angola, the DRC, Mozambique, and Zambia has the capacity to supply the whole region with electricity [16,32]. Thus, energy, like water resources, can play an important role in regional integration, inclusive economic development, and poverty alleviation. This strengthens the argument for regional resource management as opposed to national management. The region currently shares power grids whose electricity is generated from shared watercourses. However, biomass remains as the main source of energy as only 24% of the total population and 5% of rural people have access to electricity [22,33]. Over dependency on biomass energy has contributed to massive deforestation and desertification in the region [3]. Regional hydropower potential is estimated at about 1080 terawatt hours per year (TWh/year), but the current level of exploitation is less than 31 TWh/year [32]. The SADC region formed the Southern African Power Pool (SAPP) in 1995 as an initiative to support and strengthen regional cooperation and infrastructure development through shared energy resources [33]. However, lack of investment is the major challenge faced by the regional grouping. The other challenge of the SAPP is that the decentralisation of energy generation is dependent on the regional powerhouse, South Africa, which currently supplies the region with energy resources [22].

Demand for energy is increasing in the region due to population and industrial growth and urbanisation, creating a shortage that has caused power blackouts frequently experienced in the region. Current electricity generation is failing to meet local demands (Table 2), as evidenced by load shedding in some Member States, causing energy insecurity. Energy security refers to an uninterrupted availability of energy sources at an affordable price. Long-term energy security is the timely investments to supply energy in line with economic developments and environmental needs, and short-term energy security refers to the ability of the energy system to react promptly to sudden changes in the supply demand balance [32]. Yet for the SADC region, the average outage of electricity in 2008–2009 was 6.70 h, with corresponding losses of 5.4% of annual sales [34]. Table 3 shows that present capacities for electricity generation in some regional countries hardly meet local demand [35]. According to the SADC Regional Infrastructure Development Master Plan (RIDMP) of 2012, assuming an average economic growth rate of 8% per annum, the energy demand is expected to increase to more than 77,000 MW by 2020 and to over 115,000 MW in 2030, exerting more pressure on water resources [36].

Table 2. Energy supply and demand in some SAPP member countries.

Country	Installed Capacity (MW)	Net Capacity (MW)	Maximum Demand (MW)
Angola	2210	1805	1599
Botswana	892	460	610
DR Congo	2442	1485	1381
Lesotho	72	72	150
Malawi	351	351	326
Mozambique	2308	2279	830
Namibia	501	392	629
South Africa	46,963	41,074	36,170
Swaziland	70.6	70	221
Tanzania	1380	1143	935
Zambia	2128	2029	1987
Zimbabwe	2045	1600	1671
Total	**61,362.6**	**52,760**	**46,509**

Source: SARDC, 2016.

Table 3. Practical models and tools for WEF nexus assessment.

Model Categories	Model Types	Spatial Analysis
Crop models	▪ Agricultural Production Systems Simulator (APSIM).	Geographic Information Systems (GIS)
Economic models	▪ Water Energy Food Nexus Rapid Appraisal Tool	
Energy models	▪ Long-range Energy Alternatives Planning system (LEAP) ▪ RENA's Preliminary Nexus Assessment Tool	
Water models	▪ Water Evaluation and Planning system (WEAP) ▪ Soil and Water Assessment Tool (SWAT)	

The region has the potential to generate ~20,000 TWh and 800 TWh per year from solar and wind resources, respectively [32]. However, current power generation from both solar and wind in the region was at ~1% of potential. This highlights a huge gap in terms of untapped potential. While the potential for solar energy generation is evenly distributed across the region, countries such as South Africa and Namibia have been leading in terms of solar energy generation, with South Africa having the largest solar plant in the region, as well as attracting the most foreign direct investment in the area [32,35]. With respect to wind potential, this is not evenly distributed. The potential for wind generation is mostly confined to western and eastern coastal areas, as well as mountainous countries such as Lesotho. The development of solar and wind potential in the region would benefit from South Africa, which is already leading in this respect. The fact that South Africa is no longer pursuing its nuclear energy projects is good news for the SADC region as independent power producers are now engaging with the Department of Energy (DoE) to be able to invest more in solar and wind energy. A coordinated regional framework could also help to attract much needed foreign direct investment and expertise to drive the development of solar and wind energy generation. A coordinated regional framework may also reduce dependency on expensive coal-based power generation, reduce the cost of energy, thus promoting industrialisation and greater grid penetration, and reduce water use in power generation, hence freeing up water to contribute to other regional development goals.

3.3. Agriculture Potential of the SADC Region

In WEF nexus circles, food is taken as a proxy for agriculture and land. Agriculture is a source of livelihood (directly and indirectly) for over 60% of the population of the SADC region, thus, the performance of the sector significantly affects economic growth, poverty reduction, and food security [37]. Agriculture also contributes an average of 17% to the regional Gross Domestic Product (GDP); this increases to over 28% when middle-income countries are excluded [37]. Despite its strategic regional importance, the average growth rate of the sector of about 2.6% per annum, is way below the Regional Indicative Strategic Development Plan (RISDP) and Africa-wide Comprehensive Africa

Agricultural Development Programme (CAADP) targets of at least 7% and 6%, respectively. In addition, despite the importance of agriculture in the region and the fact that 76% of freshwater resources are allocated to the sector, current annual performance of the sector is insufficient to ensure regional food security and economic growth [23]. Reasons for the low growth rate include low investment, recurrent droughts, poor agronomic practices, and lack of access to credit and inputs by small-scale farmers [23]. This has negatively impacted regional goals aimed to boost productivity and competitiveness of the sector, as well as regional food security.

Food and nutrition security are multidimensional and complex and exist when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food, which meets their dietary needs and food preferences for an active and healthy life [11]. The first SADC RISDP prioritised food and nutrition security, as well as environment and sustainable development, as important areas for regional cooperation and integration. In the revised RISDP 2015–2020, food and nutrition security were identified as part of special programmes of regional dimension [38]. The revised RISDP 2015–2020's special objectives related to agriculture, food, and nutrition security and natural resources sectors are to increase production, productivity, and competitiveness of the sectors as drivers for achieving food security and sustainable economic development in Southern Africa [38]. Furthermore, agriculture, food and nutrition security, and natural resources form part of the focus areas identified to contribute to the ultimate eradication of poverty as indicated in the SADC Regional Poverty Reduction Framework [38]. The strategic food and nutrition security plans were elaborated in the 2014 Regional Agricultural Policy (RAP) for operationalisation. These stress the importance of improving the performance of the agricultural sector across the region to meet the food security and sustainable economic development objectives [27]. However, high agricultural production does not always guarantee regional food security as this is affected by many other factors such as affordability and accessibility, among other factors. Figure 3 presents selected access and utilisation dimensions of food security in the SADC region. These indicators highlight that food security remains a challenge in the SADC region as the levels shown in the trends are much higher than commitments made at the continental level to reduce hunger and malnutrition. For example, African Heads of State and Government in the 2014 Malabo Declaration and Africa Regional Nutrition Strategy 2015–2025 committed to reducing stunting to 10% and undernutrition (wasting, underweight and undernourishment) to 5%. A lack of coordinated WEF nexus planning would threaten stability.

There is also debate on the benefits of exporting agricultural produce and the implications thereof on domestic food security. Export of agricultural produce also represents the export of water. However, in several SADC states, agricultural exports are a key source of foreign currency, which then allows the country to offset some of its import costs for goods that are not locally produced. The use of indices such as water productivity could be useful in conducting cost-benefit analyses for agricultural exports.

The region's plans for increasing agricultural productivity are underpinned by availing more land for crop production, particularly cropped area under irrigation. This alludes to land use changes in some cases and increasing the amount of water withdrawals and associated energy outlays needed for irrigation. With increasing populations and urbanisation, as well as energy and water shortages, food insecurity challenges are expected to worsen. The RISDP and CAADP goals of increasing agricultural productivity through increasing the irrigated area would require more energy and water with the potential for significant trade-off with other sectors if not managed well [38]. In expanding the area under irrigation, the region should consider adopting the WEF nexus for integrated resource planning and management. The WEF nexus has the potential to rectify the present scenario where agriculture accounts for most of the available water withdrawals yet food insecurity remains a major challenge. Although agriculture will always have a larger share of water withdrawals, improved agriculture water management will result in water savings and release more water to other sectors.

From a strategic perspective, climate models estimate a decrease of about 20% in annual rainfall by 2080 in southern Africa [13]; this challenges the sustainability of irrigation expansion in a water scarce future. Either way, adopting a WEF nexus approach offers opportunities for coordinated planning to increase efficiencies and develop a WEF nexus sensitive agricultural plan. At a regional level,

this would mean directing investments in irrigation to countries that have still not fully utilised their irrigation potential. This would require a shift away from nationally focused investment and food security initiatives, to a regional investment and food security approach.

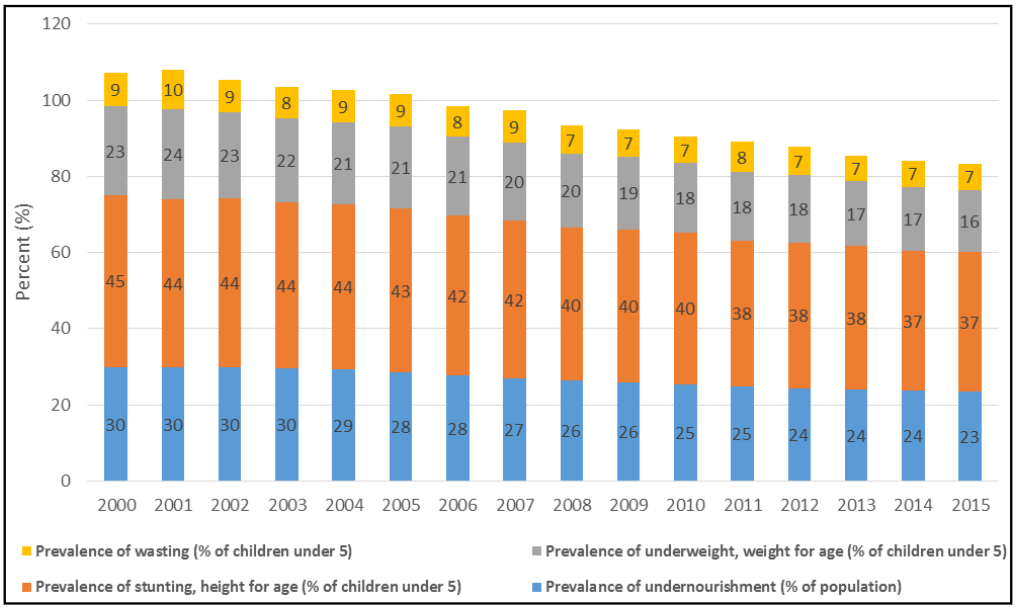

Figure 3. Selected food security access and utilisation indicators for the SADC region.

The high water use in the agriculture sector continues to be of concern to the region. Increasing population growth, urbanisation, and industrialisation are also increasing water requirements from other sectors such as domestic use, industrial use, and energy generation. Irrigated agriculture on large estates for the export of fruit and cash crops has come under scrutiny in recent years, with calls to reduce agricultural water use in the sector [3]. Biofuels production, which is now being promoted in the region, could also increase agricultural water use due to the large tracts of land required to make it viable. However, commendably so, South Africa's draft biofuels regulatory framework (DoE, 2014) makes it clear that biofuel feedstock production should not be done under irrigation. This policy needs to also cascade to the region so that other member states such as Zimbabwe, who are already undertaking biofuel feedstock production, can follow suit. A WEF nexus approach offers opportunities for assessing the synergies and trade-offs for reducing agricultural water use [3]. However, the application of a WEF nexus approach is currently limited by the lack of models, indices, and/or metrics that can be used to evaluate such synergies and trade-offs. Thus, research should now focus on developing tools for evaluating WEF nexus synergies and trade-offs.

3.4. Climate Change Impacts on WEF Resources in the SADC Region

Climate change projections for the SADC region show that the greatest impacts will mostly be felt through water resources, which could severely affect food production and energy generation [39]. Annual rainfall is expected to decrease by 20% by 2080 in southern Africa, and that could worsen the challenges of water and food insecurity [13], especially in countries that already face resource scarcities. The challenges are exacerbated by population increase and industrial growth [40,41]. These already evident stressors are negatively impacting energy generation and supply, as well as food and water security, affecting the development targets of the region [35]. Thus, the WEF nexus presents an opportunity for coordinated resource management for sustainable development, promotion of regional cooperation, ensuring regional security, and reducing regional vulnerabilities.

Climate change is causing extreme changes in plant habitat distribution, impacting on the cropping and food security [42]. This is mostly due to low rainfall, increased rainfall variability, and increased

frequency and intensity of drought and floods. The region is now marked by a great spatio-temporal variability in climate and water resources, particularly in the southern drier countries [13]. As water is key to the WEF nexus, the decrease in rainfall totals will consequently impact on energy generation and food production, compromising regional security.

The recurrence and intensity of droughts and floods is further worsening the vulnerability of the region, threatening to reverse economic gains made in the past [23]. Transboundary resources of the SADC region present an opportunity for regional cooperation in resource planning and are a pathway to promote climate change resilience and reduce those vulnerabilities. For example, the impact of the 2015/16 El Niño Southern Oscillation (ENSO) drought affected all regional countries, causing more than 40 million people (14% of the SADC population) to be food insecure [23]. Dam water levels declined, and crop yields reduced, causing energy and food insecurity [43,44]. In addition, water levels in Lake Kariba (shared between Zambia and Zimbabwe) were reduced to 12% of their capacity in February 2016 compared to the 53% recorded at the same time in 2015 during the drought period [45]. As a result, potential annual power generation was reduced by more than 50%. Similarly, in October 2015, Tanzania was forced to switch off all its hydropower plants due to low dam water levels [23], causing a decline of 20% in hydro-power generation. Tanzania has since converted some of its hydroelectricity plants to natural gas [23]. At the SADC level, available operating capacity in 2016 stood at 46,910 MW against the demand of 55,093 MW [23]. The 2015/16 drought was so severe that it also caused 643,000 livestock deaths, and an overall maize (the staple crop in the region) deficit of 5.1 million tonnes, which is a 10% decrease in production compared to the previous year and a 15% drop compared to the five-year average [23]. Consequently, the region had to declare a drought emergency and launched a US$2.7 billion drought relief appeal to the international community [23].

Rainfall anomalies in the region are evident through the variations in rainfall received during the 2016/17 rainfall season. During the 2016/17 rainfall season, Zimbabwe received enough rainfall, resulting in the copious harvest of cereals, yet the Western Cape Province of South Africa experienced a drought, which caused dam water levels to reach acute levels to the extent that the national government had to budget US$6 million towards relief aid in the province. Southern Africa has been characterised by low rainfall and recurrent mild to extreme droughts, corresponding to an average of once in three agricultural seasons [46] and these conditions hinder agricultural production across the SADC countries, particularly South Africa. Such droughts are affecting the majority of farmers who continue losing high volumes of crops and livestock.

3.5. Regional Institutions and Policies Related to the WEF Nexus

Institutions and policies have been established the SADC region to oversee and direct water, energy, and agriculture resources at a regional level. However, there is a lack of coordination among the policies and institutions, which normally results in policy spill-overs (Kling et al. [47]). There is, therefore, a need to harmonise policies in the region. The SADC Treaty is the overarching framework for the region, whose objective is to achieve economic development, peace and security, and growth; and also, to alleviate poverty and improve the livelihoods of the people, all of which are achieved through regional integration [48]. To-date, the region has ratified the following nexus-related institutions and policies:

1. The Regional Strategic Action Plan IV (RSAP IV) [38] is based on the SADC Water Policy and Strategy that aims to achieve an equitable and sustainable utilization of water for social and environmental justice, regional integration, and economic benefit for present and future generations. The RSAP IV emphasizes the importance of infrastructure development and water resource management for food security in the water-food nexus, and the stronger urgency to act in the view of climate variability and change.
2. The SADC protocol on shared watercourses [49] fosters closer co-operation for judicious, sustainable, and coordinated management, protection and utilization of shared watercourses, and advancement of SADC's agenda of regional integration and poverty alleviation. As a result,

most shared river basins have basin level agreements in place, which oversee the day-to day management of the basins with assistance from the SADC Water Division. Current shared river basin agreements include the Limpopo Watercourse Commission (LIMCOM), Okavango River Basin Commission (OKACOM), Orange-Senqu River Commission (ORASECOM), and Zambezi River Basin Commission (ZAMCOM).

3. The Southern African Power Pool (SAPP) is a grouping that was established in 1995 guided by the Protocol on Energy [50], which highlights the development and updating of a regional electricity master plan, and the development and utilization of electricity in an environmentally sound manner, whilst emphasising the need for universal access to affordable and quality services. The mandate of the SAPP is to enhance regional co-operation in power development and trade, and to provide non-binding regional master plans to guide electricity generation and transmission infrastructure delivery.
4. The SADC Regional Agricultural Policy (RAP) [37] envisages integrated approaches on water resources management and emphasises the importance of improving agriculture performance to meet the food and water security, as well as attaining sustainable economic development objectives at a regional level. The RAP oversees the upgrading and expansion of water infrastructure for agriculture, data collection for dams, irrigated areas, and irrigation management. The SADC's Regional Indicative Strategic Development Plan (RISDP) (SADC, 2003) is derived from the Africa-wide Comprehensive Africa Agricultural Development Programme (CAADP) that promotes the doubling of the irrigated area from 3.5 to 7% by 2025. The CAADP [51] provides a common framework for stimulating and guiding national, regional, and continental initiatives on enhanced agricultural productivity and food security.
5. The WEF Nexus Action Plan recognises the role of the nexus in adapting to the challenges posed by population growth and climate variability and change, as well as in optimising resource use to achieve regional goals and targets.

4. Results and Discussion

4.1. Major Challenges in Implementing the WEF Nexus

Despite institutional and policy achievements, there is little movement on the ground to show WEF nexus implementation as focus is either at the national level or at the basin level. There is still more that can be done on the optimal use of resources and to increase productivity to meet the demands of a growing population in southern Africa. Although projections point to a stronger regional WEF integration, at the moment, progress is hindered by policy sections that allow countries to retain the right to develop and implement their own national plans without being obliged to conform to the regional master plan [22]. The issue of political sovereignty is still strong at the national level, which slows genuine cooperation and integration as there is little evidence of commitment by Member States to implement the WEF nexus at a regional level. For example, each Member State is pursuing national goals to achieve national food, water, and energy security. While national focus may have positives, the shared nature of resources suggests that some investments may achieve a greater impact at a regional rather than national scale. For example, countries such as Zambia have a comparative advantage in maize production, while further north, increased water availability could be used for more power generation for the region. Also, some Member States are delaying rectifying protocols on shared watercourses as they do not envisage the need at the moment. Yet regional cooperation in development programmes does not remove national sovereignty, but fosters integrated economic development and poverty alleviation. However, current policies and strategies promote action-research to develop and to sustainably implement resilient water-related infrastructure and develop innovative technologies to direct practice. The adoption of regional policies by some countries has seen a rise in agriculture expenditure, which has increased towards the recommended 10% over the past decade (particularly in Malawi, Zambia, Zimbabwe, Mozambique) [52], but investment in agricultural water management is very low. Agriculture uses more than 70% of the available water resources in the SADC

region and this has created an imbalance in the nexus as the energy sector has been starved of water, creating an energy crisis [29].

Drought recurrences have also contributed to the slow implementation of the WEF nexus as there will not be enough water for electricity generation and irrigation. The high vulnerability and low productivity evident throughout the region are a tough combination for smallholder farmers who are the majority of the population and are exposed to climate impacts. The high levels of poverty, as well as political instability, in some countries of the region are also a drawback to the implementation of the nexus as opening up may trigger economic and political migration and flood some countries.

The urgency to adopt and implement the WEF nexus is also due to the increasing population, which is exerting pressure to produce more food to feed the growing population. Improving living standards are also contributing to the high demand of water, energy, and food. The high population growth rate in the region is causing urbanisation as young people flock to urban areas in search of a better life, resulting in a high demand of WEF resources. Economic and political instability in some areas in the region is fueling migration to more stable areas, further exerting the demand for WEF resources in receiving areas. These growing pressures on WEF resources require evidence-based solutions of WEF nexus implementation for better resource management to meet the demands of the growing population.

4.2. Potential of the WEF Nexus in Promoting Regional Development and Poverty Eradication

Broader and natural boundaries determined by natural resources go beyond political boundaries and sovereignty and increase the potential for effective trade-offs between the WEF as they improve resources management in a more effective manner [53,54]. This is particularly relevant in the SADC region, where resources are shared among countries. The established institutions and policies should now move from rhetoric, documents, and offices into practice and move towards inclusive development and socio-economic security.

Besides the endowment of vast natural resources, more than 60% of the people live in poverty as resources are currently underutilised. As already mentioned, of the 2300 km^3 of renewable freshwater water resources that are available yearly, only 44 km^3 is abstracted and 14% is stored [22]. The adoption of the nexus approach would benefit the southernmost countries of the SADC region, which are water scarce. Also, of the 50 million ha of irrigable land, only 7% is irrigated, and out of a possible 150 GW of hydropower potential, only 12 GW is harnessed [32]. The potential to ensure water, energy, and food security in the region is thus immense, while still operating within the sustainable use of freshwater resources. However, successful implementation of the WEF nexus would require investment and commitment by SADC countries. Other drivers of the WEF nexus such as skilled labour, institutions, and markets are available in the region.

Institutions and policies that have been established need to be linked to each other, for example, through the Revised Regional Indicative Strategic Development Plan (RISDP 2015-020), as the region moves towards joint planning to increase synergies between the three nexus sectors. Joint planning would improve hydropower development and irrigation expansion in a more coordinated manner for sustainable development. However, a lot must be done to unpack the potential of the WEF nexus approach within the SADC region to effectively exploit the many interlinked development opportunities. These would be particularly relevant if the stresses placed on water, energy, and food resources by climate change and other factors are put into consideration. Climate change does not recognise political boundaries nor sovereignty, as was the case with the 2015/16 drought, which affected the whole region. A regional nexus approach increases regional resilience against climate change impacts and reduces vulnerability, which permeates the region.

4.3. Implementation and Monitoring of the WEF Nexus

WEF nexus implementation and monitoring has long remained a rhetoric ambition without any guidelines to provide real world solutions [5,55]. Most initiatives have focused on sectoral development due to the lack of WEF guidelines and scientific evidence, and this has resulted in

unintended consequences in most cases [56]. Successful implementation and monitoring of the WEF nexus can be achieved through a set of nexus linked targets and indicators for the three resources through input-output modelling approaches. Sector-based analytical models and tools to assess sector targets and indicators have been developed and successfully tested (Table 3). The challenge now is to link these sectoral models and tools to provide scientific evidence for integrated planning and the identification of trade-offs and synergies of the nexus. The WEF nexus is thus a mechanism to transfer the biophysical systems to the human domain in a more coordinated manner [47,57]. Therefore, these models could be biophysical or economic.

With the support of harmonised WEF institutions and policies, as well as evidence-based targets and indicators, the WEF nexus has the potential to lead a more optimal allocation of resources, promote inclusive economic growth, and ensure environmental and health sustainability [58]. The WEF nexus is the rediscovery by experts working in silos of the need of an integrated approach to resource management [5].

4.4. Integrated WEF Nexus Assessment Models

Figure 4 is an illustration of the integrated nexus assessment models and tools, showing the relationship between natural systems and human decisions, policies, and values, as represented by the three interlinked model categories. The illustration demonstrates the interaction between the human system or economic models (policies and institutions) and the physical and natural systems. Each system is represented by components from which models that assess the WEF nexus are derived. The models are important in setting and assessing targets and indicators for the WEF nexus. The economic or human system is divided into two distinct but interconnected categories, decision-making and the value of ecosystem services as they are altered for human wellbeing [56]. The illustration stresses the importance of an integrated nexus approach for human wellbeing and sustainable development. Thus, WEF nexus decision-making is supported by integrated analytical tools or integrated nexus assessment models. An assessment model that could drive the nexus in an integrated manner is the multiscale integrated analysis of societal and ecosystem metabolism (MuSIASEM) [59]. The MuSIASEM integrates sector models that include the Agricultural Production Systems Simulator (APSIM), Water Evaluation and Planning system (WEAP), Water Energy Food Nexus Rapid Appraisal Tool, RENA's Preliminary Nexus Assessment Tool Soil and Water Assessment Tool (SWAT), Water Accounting Plus (WA+), and Physical, Economic, and Nutritional Water Productivity (Table 3). The MuSIASEM has been successfully applied as a simulation tool for case studies in Mauritius, the Punjab, and South Africa [59]. As WEF resources are spatially distributed, the models are connected through a Geographic Information System (GIS). There are limitations in the way that the MuSIASEM links the behaviour of specific populations and the physical ecosystems in which they live, especially if the spatial and temporal scales of such analyses are varied. This limitation is an area that needs further research, especially since the WEF nexus is in its infancy.

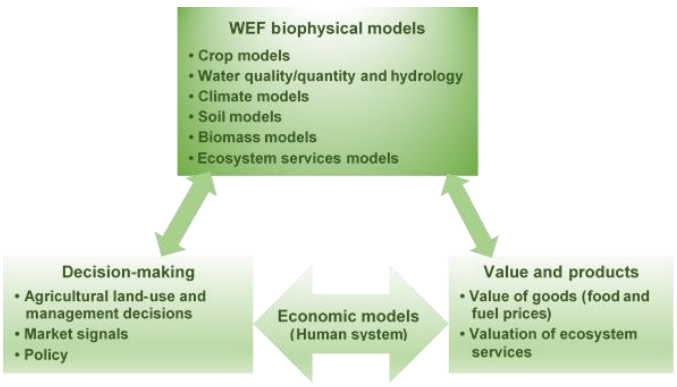

Figure 4. Integrated WEF nexus assessment models. Adapted from Kling et al. [47].

4.5. The WEF Nexus Framework for SADC Region

Figure 5 illustrates an idealistic SADC fit in the WEF nexus conceptual framework showing the four fundamental WEF nexus components and their elements (action fields, finance, governance, and innovation). The proposed framework is an initial step towards the adoption and implementation of the WEF nexus at a regional level considering similar challenges besetting regional countries, as well as the shared resources within the transboundary river basins. The framework touches upon the common issues in the region that include challenges and governance, and provides the action fields in order to achieve the desired outcomes through the WEF nexus. Tools and models provided in Table 3 are used to execute the action fields. The framework emphasises the role that the WEF nexus could play in regional integration, as the region's resources are generally transboundary. The approach could be vital in poverty eradication and resilience building in the advent of climate change and could improve the livelihood of vulnerable people. The WEF nexus framework considers the following elements [10,60]:

1. Strengthening policy and governance to manage the WEF nexus and provide political commitment.
2. Cooperation and commitment by member countries in the implementation of the WEF nexus in shared resources for regional socio-economic security and poverty eradication.
3. Promotion of public awareness to develop a culture of regional integration and recognition of the role of broader and natural boundaries in regional socio-economic security and improve the livelihoods of people.
4. Provision of scientific evidence and tools to identify trade-offs between nexus components and support the development of effective, integrative resource allocation strategies.

With the political will (governance), regional WEF challenges (trends) can solved by applying nexus assessment models (Figure 4) to action plans to achieve desired outcomes (Figure 5).

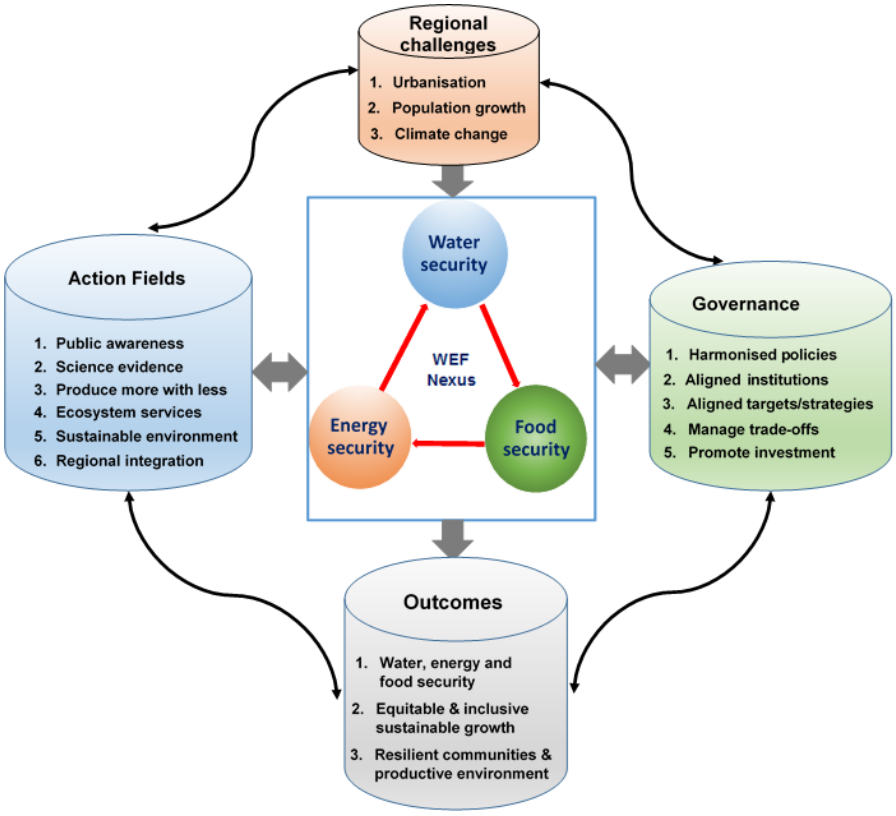

Figure 5. Regional WEF nexus framework for the SADC. Source: Developed by authors.

5. Conclusions

The WEF nexus offers opportunities to effectively attain sustainability through interdisciplinary cooperation at a regional level, particularly in southern Africa, where resources are shared. The nexus offers inclusive, transparent, intergovernmental approaches for all stakeholders, and supports the UN SDGs, using scientific and evidence-based policy, monitoring, assessment, and cooperation models. The WEF nexus thus offers opportunities to promote peace, regional cooperation, and harmonisation of legislations, policies, and strategies in a region of transboundary resources. Sectoral policies that are not linked to each other promote unsustainability and unbalanced resource development. The regional conceptual framework and the given models present opportunities for developing comprehensive analysis approaches, identifying synergies in the nexus, and assessing multiple benefits and trade-offs across ecosystem service sectors. Challenges in southern Africa are generally similar in nature among Member States and an integrated approach to resource management at a regional level may bring the desired outcomes. As the vast and unexploited resources within the region are unevenly distributed within the transboundary river basins, the WEF nexus could be a pathway for resilience building and a reduction of vulnerabilities that permeate the region. However, successful implementation of the nexus at a regional level requires commitment from Member States, supported by technological innovations that allow the production of more food with less resources. Adoption of the nexus approach would be a step forward towards attaining the SDGs on poverty eradication, zero hunger, availing water to all, and provision of clean energy (goals 1, 2, 6, and 7 respectively). The shared and transboundary nature of SADC's resources implies that there are greater gains and more prospects of success if developmental efforts are focused at the regional level as opposed to the national level. Unlocking development at the regional level would ultimately allow greater progress at the national level and allow for genuine integration and inclusive development. Incorporating the nexus thinking in the development of agriculture investment plans would be worthwhile for sustainability.

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