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Policy coherence assessment of water, energy, and food resources policies in the Tana River Basin, Kenya

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ABSTRACT

Water, energy, and food resources are closely related in the water-energy-food (WEF) nexus, a tightly connected system in which impacts in one sector leads to changes in the other sectors. The WEF nexus approach studies these interactions to better understand their connections and implications across sectors, and is focused on making research practicable for policy. There is a clear lack of policy coherence studies to provide practical recommendations to achieve integrated resources management. This is true in the Tana River Basin (TRB), which provides abundant water, energy and food resources to the national economy and development of Kenya. This work carried out a WEF policy coherence assessment of the Tana River Basin. Results show that there are synergies and trade-offs across all resources sectors and their policy objectives. Water policies (e.g. to secure water availability) are generally evaluated as win-win, thus being supportive of attainment of goals in other policy sectors. Food policies (e.g. to develop the agricultural sector) show the highest number of trade-offs, suggesting these policies could be redesigned to minimise the trade-offs with other resource policies. This work highlights specifically which policies are relatively more or less supportive for holistic resources management in the TRB. In particular, the only TRB-level policy analysed (which is cross-resource in its ambition) shows synergies with national policy, offering opportunity for leveraging benefits and increasing implementation efficiency across resources. Strengthened cross-sectoral collaboration, joint workshops, and the establishment of a national cross-sectoral taskforce to develop aligned policies are recommended. This work provides a basis for similar studies across Africa, and promotes research that is of practical relevance.

1. Introduction

Water, energy, and food (WEF) are considered crucial components of sustainability as highlighted in the United Nations' 17 Sustainable Development Goals (SDGs; Huntington et al., 2021). WEF resources are mutually interconnected with the implication that one sector should not be assessed independently from other sectors (Sušnik and Staddon, 2022). The WEF nexus approach has stimulated policy, academic, and societal conversation, including considering interconnections with the economy, livelihoods, and ecosystems (De Fraiture et al., 2010; Sušnik and van der Zaag, 2017; Amorocho-Daza et al., 2023). Globalization, climate change, urbanization, and population growth have been the main contributors to major environmental damage and the depletion of resources (Hoff, 2011). These conversations are framed in the recognition that the Earth's resources are scarce and finite, subject to further depletion, and vulnerable due to the effects of climate change and world's population expansion (Richardson et al., 2023). The United Nations has indicated that global population will increase to about 9.7 billion by 2050, placing additional strain on already stressed resources and hindering achievement of the SDGs. It is estimated that a 60 % increase in food production would be needed to feed the world's rapidly population expansion by 2050, and a further 35 % increase in energy output will be necessary by 2035 (Hoff, 2011; FAO, 2014). In addition, the COVID-19 pandemic and ongoing global conflicts have set back progress on achieving the SDGs by several years. Due to the interconnection of the WEF resources sectors, the adoption of integrated policy and planning frameworks involving multiple sectors to ensure efficient and effective equal share of resource utilization is required (Hoff, 2011).

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While the WEF nexus has gained prominence as a means to improve understanding of the relationships between resource systems (Albrecht et al., 2018), and that a systems-based viewpoint is useful in understanding the interconnections between WEF sectors (cf. Kurian, 2017), there are few analyses which consider the practical issues of how WEF interconnectedness is recognised and embedded in policy and planning for resources management. By neglecting such considerations, policy development for resources security could be inefficient, ineffective, or counter-productive. To this end, there have been recent calls for a greater shift from 'nexus thinking' to 'nexus doing', making research more relevant for integrated natural resources policy development (Simpson and Jewitt, 2019), especially in southern Africa (Mabhaudhi et al., 2018). There are very few studies to this end, with the governance analysis work of John et al. (2023) being one recent example of a practically-oriented study.

In Kenya, challenges of water scarcity, food insecurity, and inadequate access to electricity are dominant (Desa, 2015). To address these challenges, there is an urgent need to understand WEF nexus interactions and integrate policies across these sectors to enhance resource access and security to increase societal resilience and ensure sustainable resource management. Although the WEF nexus approach is now promoted in Kenya, inadequate policy frameworks, which address societal water, energy and food needs in the context of population pressure and rapid urbanisation provide a challenge to integrated resources management (Wakeford, 2017). Therefore, to ensure access to water, energy, and food resources in the future, the country must carefully manage population and socio-economic developments through the integration of policies and sectoral collaboration (Wakeford, 2017).

In the Tana River Basin (TRB), there are several WEF nexus related challenges. The basin is a major resource base contributing to food, water and electricity security in Kenya. It contributes to energy production for local access and for export, contributing to the economy, as well as water availability via hydropower developments, irrigation schemes, and water supply schemes (Baker et al., 2015; Botzen et al., 2015). The pool of resources in TRB has attracted the interest of a multitude of stakeholders who aim to convert the available resources into useful products for greater economic development and sustainable resource resilience, such as the aforementioned hydro-power development, large water storage reservoirs and large-scale irrigation schemes. The TRB is a key driver in Kenya's 2030 vision for water provision to enhance irrigation, domestic supply, generation of hydro-power, and land expansion for agricultural production (Baker et al., 2015). In this regard, the Government of Kenya is planning to increase the resource base in TRB through expansion of hydropower projects, building more water reservoirs, and upgrading the existing irrigation schemes on an estimated 292,100 ha of land by 2030 (Baker et al., 2015). Despite these efforts, poor coordination between relevant stakeholders, and lack of understanding of policy interactions across sectors (horizontal integration) and between national and local levels (vertical integration) have hampered effective resources utilization and multi-sectoral collaboration at the river basin level (Langat et al., 2017). From this background, the primary research question investigated in this research was to ascertain how the current water, energy, and food policies are interconnected across sectors and to explore some of the opportunities to improve policy coherence for more effective natural resources management in Tana River Basin, Kenya. In addition, the current water – energy – food nexus policies, their level of coherence, existing gaps, and overlaps were investigated, and recommendations that can be adopted to enhance WEF nexus policy improvement across sectors in TRB are made.

These inadequate and poorly understood policy frameworks and incoherent policies across the water, food, and energy sectors, present a challenge to effective implementation of projects intended to support development and economic growth in the TRB in a sustainable way (Wichelns, 2017). Therefore, it is important to carry out a coherence analysis of WEF resource policies across the basin. By analysing and understanding the key policy interactions potential challenges can be identified and overcome and synergies sought to promote effective integrated resource planning and more efficient multi-sectoral resources management. In this context, this study carries out a detailed cross-sectoral WEF resources policy coherence analysis in the TRB. The study will shed light on policy coherence in the TRB more generally, providing a basis towards evidence-based 'nexus doing' in the policy and resource management domain.

2. Case study and methods

2.1. Case study description

The TRB (Fig. 1) is one of Kenya's major river basins, contributing c. 32 % of the nation's overall river runoff (Baker et al., 2015). It is located in south-eastern Kenya and has an area approximately 126,028 km^2 (Langat et al., 2017). At its headwaters in the hilly Aberdare, Mount Kenya, and Nyambene highlands. The Tana River meanders through heavily forested landscapes, traversing agricultural land before flowing through grasslands. The river flows for 700 km through flood-prone semi-arid areas, ending in a floodplain at Ungwana Bay in the Indian Ocean (Langat et al., 2017). The Tana River exhibits a dynamic flow pattern, with its highest flows occurring during the long-wet season, with the lowest flows during the dry season (Baker et al., 2015). The management of the TRB falls under the Water Resources Management Authority (WARMA; Langat et al., 2017).

The TRB is known for its significant agricultural productivity, serving as a key agricultural region in Kenya (Odhengo et al., 2012; Baker et al., 2015; Agwata, 2006). Fertile soils and a favourable climate support various agricultural activities, including crop cultivation, livestock rearing, and horticulture. The basin plays a critical role in food production and contributes significantly to the national economy through agriculture (Al-Saidi and Elagib, 2017). Apart from its agricultural significance, the TRB has substantial hydropower potential (Baker et al., 2015). Several large hydropower plants have been built along the Tana River, such as the Seven Forks Dams, which generate hydroelectric power to meet the country's energy demands. These dams also serve as water reservoirs for irrigation and other water uses (Baker et al., 2015).

2.2. Methodological approach

2.2.1. Policy coherence approach

According to Nilsson et al. (2012) policy coherence "*is a quality of policy that consistently eliminates conflicts and fosters synergy across and among various policy domains in order to accomplish the results linked to mutually agreed-upon policy goals*". Munaretto and Witmer (2017) define policy coherence as "*an aspect of policy that refers to the coordinated efforts made at various administration and geographical scales to minimize conflicts and foster synergies between and across particular policy domains*". An updated Nilsson's framework developed by Munaretto and Witmer (2017), is shown in Fig. 2, and forms the basis for the approach adopted in this work.

Following to the approach in Fig. 2 (bounded by the red box), policy coherence analyses the content of policy documents to identify and resolve disputes that may arise during their implementation. In the updated approach Munaretto and Witmer (2017) and Munaretto et al. (2018) outline a scoring system that provides direction *and* strength of the interaction between policy documents. A scoring scale between −3 and +3 is used to assess the coherence between policy objectives and instruments in two policy documents (i.e. a scored pairwise comparison between documents, with the results presented in a matrix; Munaretto et al., 2018). A score of −3 means policy goals/objectives are strongly conflicting, implying that achieving goal "A" would prevent achievement of goal "B". On the other side, +3 means that two goals are inextricably linked – achieving one, will by default lead to achieving the

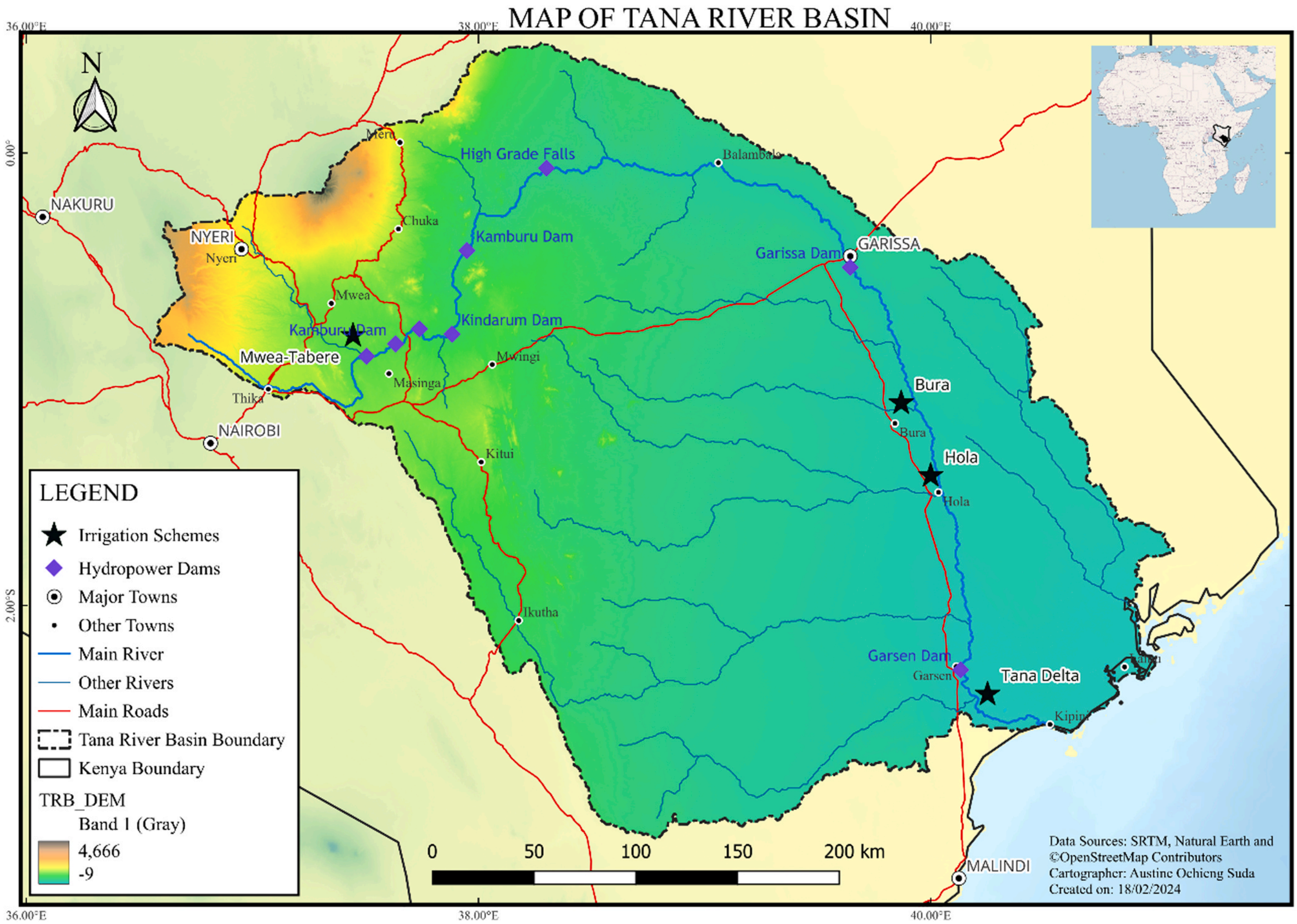

Fig. 1. the Tana River Basin, Kenya, indicated by the broken black line. Altitude is indicated by the graded colouring from red to blue. Rivers (water) are indicated by blue lines, hydropower dams (water and energy) by purple diamonds, and irrigation schemes (water and food) by black stars.

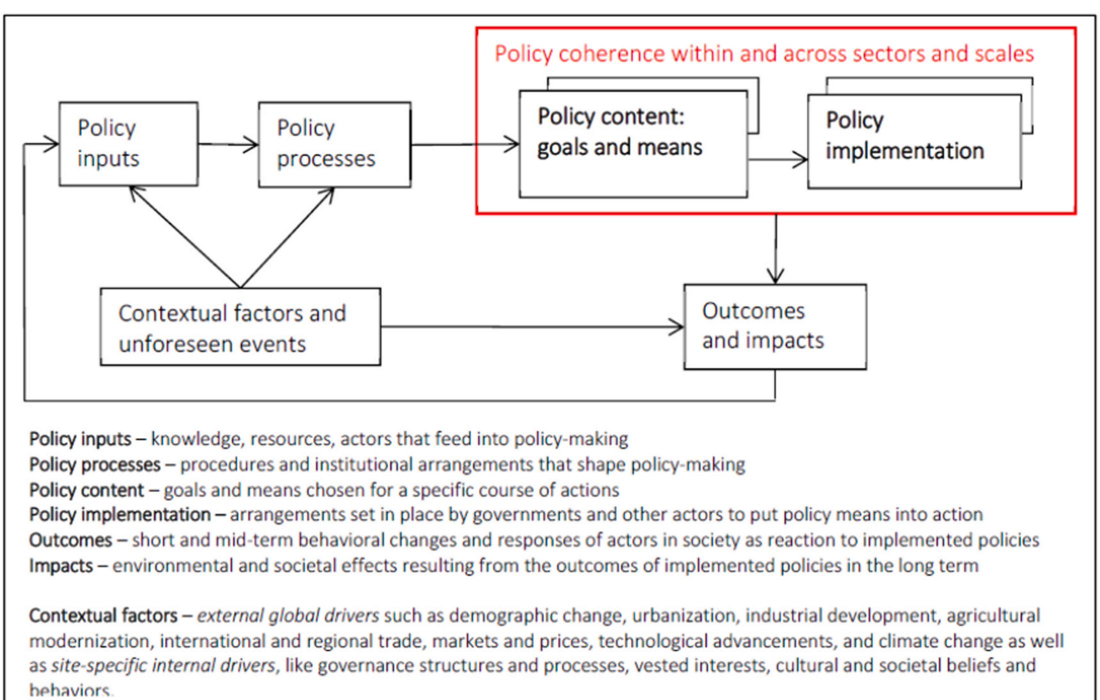

Fig. 2. The updated Nilsson policy coherence framework adapted from Munaretto and Witmer (2017). Red box defines the scope of analysis in this study.

other. A score of 0 means there is no interaction between goals/objectives.

The following steps were followed during the policy coherence analysis process:

1. Collection of primary and secondary policy documents such as government plans, strategies, Act of parliaments, and integrated/development plans. These were stored in a policy inventory Excel data sheet (Supplementary Information [SI] S1). Documents related to WEF resources development were collected ranging from National, County, and Basin level.
2. Policy document content analysis was performed to map the key policy goals, means, and objectives in the WEF resource sectors and other related policy areas. The information was stored in the policy inventory Excel data sheet (SI S1). This was done by manual analysis of policy document content by reading documents, and identifying and mapping key policy goals, means, and objectives to WEF resources sectors and other related policy areas;
3. Selection of policy objectives. The main objectives were selected from the policy documents in line with WEF nexus policy areas. The selection of the objectives was informed by the importance of the objective to the TRB, relevance of the objective to water, food, and energy, and the potential interaction with WEF nexus policy sectors at the national, county, and basin levels.
4. Codes were assigned to each selected policy objective. Assessment of policy interaction across the WEF nexus sectors was conducted to

Table 1
WEF nexus policy documents analysed.

Policy Type	Sector	Document	Description	Policy life span	References / link
Act/Law	Water	Water Act, 2012	Provide guidelines for obtaining, protecting, managing, and utilizing water resources. It covers the administration of water supply and sewage services, the control of water uses rights, and the creation of a water resource management body and its responsibilities.	2012–2030	http://kenyalaw.org/kl/fileadmin/pdfdownloads/RepealedStatutes/WaterAct_Cap372_.pdf
Plan	Water	Water resource Authority Strategic Plan	Improves the management of water resources at both national and basin levels, safeguards and reinforces the collection and administration of water resources information across various sectors	2018–2022	https://faolex.fao.org/docs/pdf/ken207659.pdf
Plan	Water	National Water Master Plan	Advocates for the development of irrigation plans to boost agricultural growth across the country including desert and semi-arid areas.	2013–2030	https://wasreb.go.ke/national-water-master-plan-2030/
Framework	Energy	National Energy Policy	Provide reliable, affordable, and environmentally friendly energy that can support economic growth at the national and local levels. At the same time, this work entails maintaining the environment for the benefit of generations to come.	2018–2028	https://repository.kippra.or.ke/handle/123456789/1947
Framework	Energy	Kenya National Energy Efficiency and Conservation Strategy Plan	Reduce national energy intensity by 2.8 % yearly, with the goal of achieving 30 % reduction in emissions by 2030 and achieving SDG 7 by the same year.	2020–2030	https://unepccc.org/wp-content/uploads/2020/09/kenya-national-energy-efficiency-and-conservation-strategy-2020–1.pdf
Framework	Food	National Food and Nutrition Security Policy	Improve the quality and quantity of food that is readily available to all Kenyans on a consistent basis, reduce food insecurity in the most at-risk populations by implementing innovative and effective safety measures that are linked to broader sustainable development goals, and promote health equity in the country as a whole.	2011–2021	https://mofood.portal.gov.bd/sites/default/files/files/mofood.portal.gov.bd/page/1f722343_5fdb_494d_8b62_31fc14abc1da/nothi_81_2022_12_22_91671701102%20(2).pdf
Framework	Food	Agricultural Policy 2021	Converts agricultural activities involving crops, livestock, and fisheries into economically driven development that ensure lasting food and nutrition security. It establishes a structure for fostering collaboration and communication between the National and County governments, as well as other stakeholders, to enhance agricultural growth and development.	2021–2030	https://kilimo.go.ke/wp-content/uploads/2022/05/Agricultural-Policy-2021.pdf
Strategy	Food	Agricultural Development Strategy	Implements the Vision 2030 by integrating tree crops into agricultural production and introduces water-sufficient crop species.	2010–2020	https://faolex.fao.org/docs/pdf/ken140935.pdf
Framework	Water, Food, Energy	The National Irrigation Policy	Encourages sound utilization of irrigation capabilities by expanding the irrigated area by 40,000 ha annually, aligned with Kenya Vision 2030 goals. This entails enhancing water resources for irrigation through inventive methods like water harvesting, flood control, wastewater utilization, and sustainable management of groundwater. It advocates for an all-encompassing strategy towards sustainable commercial irrigation farming.	2018–2028	https://irrigation.go.ke/download/national-irrigation-policy-2017/
Strategic Plan	Water, Food, Energy	The Kenyan Vision 2030 Strategic Plan	Elevate Kenya to a middle-income nation that offers a high standard of living with a clean and secure environment to all its citizens by 2030.	2008–2030	https://vision2030.go.ke/
Plan	Water, Food, Energy	Tana River County Integrated Development Plan (CIDP)	Ensures water resource availability and accessibility, boosts agricultural production through irrigation projects, optimizing sustainable energy sources, expands electricity distribution, and develop hydropower facilities for efficient production.	2018–2019	https://repository.kippra.or.ke/handle/123456789/421

explore the coherence of the policy objectives in the TRB. Assessment involved pairwise comparison of policy objectives across WEF nexus sectors. A scoring matrix between −3 and +3 (see description above) was used to assess the level of interaction between pairs of objectives across sectors. This interaction assessment was subjective, based on a thorough reading and interpretation of policy-pairs. The scoring of interactions between policy objectives was done by making explicit judgments, which were documented (Supplementary Information S2). Intimate local knowledge of the TRB and Kenya from one author helped in this regard. Results from the scoring assessment were documented in a scoring table.

5. Identification of Nexus Critical Objectives (NCOs). After the assessment of the main policy interactions, NCOs identification for water, energy, and food policies was conducted. This was done by selecting policy objectives from the results of assessment that showed the highest number of interactions during pairwise comparison of the WEF nexus policy objectives.

2.2.2. Data sources

Strategic policy documents and reports from national, county, and river basin levels were reviewed and analysed using the policy coherence approach (Section 2.2.1) to arrive at an understanding of the level of integration of WEF resource policies and their interconnection across sectors and between national and local scales. The findings are then used to propose policy recommendations for more effective multi-sectoral resource management in the TRB. Some of the key documents analysed include: The Tana River County Integrated Development Plan (CIDP), the Tana River County Annual Development Plan (ADP), The National Water Act (2012), The National Energy Policy, National food and Nutrition policy. In addition, the following policy plans were scrutinized: The National Water Master Plan (2016), the National Irrigation Master Plan (2017), the National Energy Policy (2019), the Tana River Basin Integrated Water Resources Management Master Plan (2018), and the Tana River Basin Climate Change Adaptation Strategy (2019). The policy documents cover the water, food, and energy sectors. Table 1 outlines the documents analysed, a brief description, and a link to the document source. It is noted that one document (the Tana River Basin Climate Adaption Strategy) is at TRB level, while all others are national scale, yet analysed in the context of the TRB. The TRB-level analysis could therefore bias results and outcomes, which may well differ if this was to be completed at Kenyan national level. Although this may be possible, the analysis in this work deliberately chose to focus on the TRB, so all results and outcomes are within this context.

3. Results

3.1. Policy coherence assessment

The selected policy documents and strategic plans (Table 1) underwent a comprehensive review process, which included the in-depth pairwise comparison of their contents.

3.1.1. Inventory of policy documents, objectives, and goals

In the first step, 11 policy documents were identified and selected (Table 1). The goals of the selected documents focus on the long-term provision and management of water resource, provision of reliable, affordable, and clean energy that can support economic growth, and enhancement of food security in the TRB. Content analysis of the selected 11 policy documents was carried out to identify the degree of relevance and potentiality of the policy goals across key important sectors. We adopted a qualitative methodology through the use of the modified Nilsson approach applied in SIM4NEXUS to carry out content analysis of the selected policy documents following the steps outlined in Munaretto and Witmer (2017). This approach focuses on policy document content to examine policy coherence by highlighting conflicts and synergies in policy formulation, both between and across particular policy domains. This can help identify potential disputes that may arise during the implementation process. The information gathered from the analysis was stored in a policy inventory Excel data sheet (SI S1).

3.1.2. Identification of the main WEF policy objectives

The WEF policy objectives in the documents were established after content analysis of the key policy documents (Table 2). During the selection process, 11 policy objectives were selected. The policy objectives from the three resource sectors include: three in the water sector; two in the energy sector; three in the food/agricultural sector; and three that span the WEF sectors. After selection, codes were assigned to each objective. Table 2 shows the summary of the identified policy objectives that have been identified and that will be used in the scoring matrix process.

3.1.3. Interactions between WEF policy objectives

The scoring matrix (Fig. 3, and see SI S2 for full justification of the scores attributed) offers an overview of what happens to a policy objective in the left-most column (affected policy) if policies in the very top row are implemented (affecting policy). For instance, what might happen to energy policy E1 if water policy W2 is implemented? The matrix gives a score of +2. That is, securing reliable water resources and implementing effective management can help to ensure clean, reliable energy provision (e.g. via reliable hydropower). A summary of some selected scores in the matrix (Fig. 3), along with their scoring justification (extracted from the SI), is given below:

- The interaction between W2 and W3 is +1. Enhanced water resources management systems enable the development of irrigation plans for agricultural development since there will be proper allocation of water across sectors at basin level.
- The interaction between E1 and W2 is +2. Provision of reliable, affordable, and clean energy can support economic growth across sectors and reinforce water resource management systems.
- The interaction between W3 and E2 is −1. Development of irrigation plans to boost agricultural growth conflicts with the reduction of national energy intensity to achieve a 30 % reduction in emissions by 2030.

Water sector policy objectives had the most positive interactions across sectors, potentially offering win-win situations. Water objectives on realization of acquiring, conserving, and using water resources (W1), water resource management systems (W2), and development of irrigation plans to boost agricultural growth (W3) had positive interactions when paired with policies in the food and energy sectors. For example, a water resource management plan with well outlined regulations can enhance the development of food security and energy efficiency in the basin because there should be well organized practices to govern water allocation across sectors (e.g. water for irrigation development or hydropower water allocation rules). In addition, food and energy policy objectives such as implementation of the vision 2030 by integrating tree crops into agricultural production and introducing water-efficient crop species (**F3**) and reduction of the national energy intensity by 2.8 % annually in order to achieve a 30 % reduction in emissions by 2030 (**E2**) were found to be synergistic. This is because water efficient crops require less water, thus improving water availability for energy generations such as hydropower development (assuming no expansion of irrigated lands). Furthermore, there will be available water for other agricultural activities such as irrigation schemes which enhances food security in TRB. There were a few conflicting interactions however. For instance, objectives on development of irrigation plans to boost agricultural growth (W3) did conflict with other sectors since the development of irrigation plans may lead to challenges such as increased pollution and environmental degradation. Irrigation requires water and energy, so an increase in irrigation may lead to an increase in water scarcity in other sectors and/or difficult in providing energy to all users

Table 2
main WEF policy objectives and codes determined after analysis of the documents in Table 1.

Code	Policy Name	Policy objectives	Description
	WATER		
W1	Water Act, 2012	Outlines rules for acquiring, conserving, using, & supervising water resources.	• It covers the administration of water supply & sewage services. • Control of water use rights. • Creation of a water resource management body and its responsibilities. • The guideline and rules for water resource utilization, acquisition and management as outlined in this policy is used in water allocation to other sectors such as energy through hydropower development and agriculture through irrigation for food security.
W2	Water Resource Authority Strategic Plan	Enhances water resource management systems across sectors (both national and basin levels)	• Improves the management of water resources at both national and basin levels. • Reinforces the collection of water resource management. • Safeguards the administration of water resources information across various sectors. • This policy objective strategically safeguards and reinforces the collection and administration of water resource management information that is applicable in the energy and agricultural sectors to enhance energy efficiency and food security respectively.
W3	National Water Master Plan	Development of irrigation plans to boost agricultural growth across the country	• Advocates for the development of irrigation plans to boost agricultural growth across the country including desert and semi-arid areas. • Enhances environmental protection and conservation • This policy objective outlines long term irrigation plans that enhance food security and equitable water usage across other sectors such as energy and environment.
	ENERGY		
E1	National Energy Policy	Provides reliable, affordable, & clean energy that can support economic growth across all levels and scale.	• Provides reliable, affordable, and clean energy that support economic across levels. • Maintaining the environment for the benefit of generations to come. • Reliable, affordable and clean energy supports efficient irrigation system, water treatment plants, food processing. This ensures, clean water and improve water management practices in agriculture.
E2	Kenya National Energy Efficiency and Conservation Strategy	Reduce national energy intensity by 2.8 % annually to achieve a 30 % reduction in emissions by 2030.	• Reduce national energy intensity by 2.8 % yearly • Achieve a 30 % reduction in emissions. • Achieve SDG 7 by 2030. • This policy objective contributes to a sustainable water management activity and optimize water usage in food production leading to food security and proper water resource management system.
	FOOD		
F1	National Food and Nutrition Security Policy	Reduce food insecurity by-implementing innovative and effective safety measures in line with broader SDGs.	• Reduce food insecurity by implementing innovative and effective safety measures in line with broader SDGs. • Improve the quality and quantity of food that is readily available to all Kenyans. • Promote health equity in the country as a whole. • Innovative and effective safety food measures ensure sustainable food system, efficient use of water and energy resources.
F2	Agricultural Policy 2021	Transforms agricultural activities into economically driven development for sustainable food and nutrition security.	• Transforms agricultural activities into economically driven development for Sustainable food and nutrition security. • Fostering collaboration & communication between the National, County governments, and stakeholders. • Enhance agricultural growth and development. • Economically driven agricultural development ensure efficient use of water in agriculture and promotes adoption of renewable sources of energy like solar power for irrigation purposes.

(continued on next page)

Table 2 (*continued*)

Code	Policy Name	Policy objectives	Description
	WATER		
F3	Agricultural Development Strategy	Implements the Vision 2030 by integrating tree crops into agricultural production and introduce water-sufficient crop species.	• Implements the Vision 2030 by integrating tree crops into agricultural production • Introduce water-sufficient crop species. • This policy ensures introduction of water-efficient crops that reduces pressure on water resources and lower energy consumption for irrigation leading to a sustainable natural resource management.
	WATER-ENERGY-FOOD		
N1	National Irrigation Policy	Utilization of irrigation capabilities by expanding the irrigated area by 40,000 ha annually in accordance to Kenya's Vision 2030 goals.	• Encourages sound utilization of irrigation capabilities by expanding the irrigated area by 40,000 ha annually, aligned with Kenya Vision 2030 goals. • Enhancing water resources for irrigation through inventive methods like water harvesting, flood control, wastewater utilization, and sustainable management of groundwater. • Advocates for a holistic strategy towards sustainable commercial irrigation farming. • This policy ensures sound and sustainable management and utilization of water resource for energy production through hydropower and agricultural development through irrigation activities.
N2	The Vision 2030 Strategic Plan	Change Kenya to a middle-income nation that offers a high standard of living with a clean and secure environment to all its citizens by 2030.	• Elevate Kenya to a middle-income nation that offers a high standard of living with a clean and secure environment to all its citizens by 2030. • For instance, Food security, water accessibility & availability and clean and affordable energy. • This policy stipulates that a well-managed water resource promotes agricultural development through irrigation for food security, promotes reliable and affordable energy through hydropower development and supply of clean and secure water for domestic use.
N3	Tana River County Integrated Development Plan	Ensures water resource availability and accessibility, boosts agricultural production & optimize sustainable energy sources for efficient production.	• Ensures water resource availability and accessibility. • Boosts agricultural Production through irrigation projects. • Optimizing sustainable energy sources through hydropower development for efficient production. • This policy outlines the counties development plans that includes sustainable water management for clean energy production, agricultural development through irrigation and clean water availability to the community though water reservoirs.

in a reliable manner. For example, the water policy objective on the development of irrigation plans to boost agricultural growth across the country (**W3**) conflicts with the energy policy objective on the provision of reliable, affordable, and clean energy that can support economic growth across all levels (**E1**) since the results of the interaction of the two policies will increase water supply for irrigation and consequently reduces water allocation for energy production leading to a decreased hydropower generation in TRB.

Energy sector policies on the provision of reliable, affordable, and clean energy (E1), and reduction of the national energy intensity to achieve a 30 % emissions reduction by 2030 (E2) had positive interactions with agriculture, food, and water. In addition, water policy objective (**W3**) and food policy objective (**F2**) provided a synergetic result after the pairwise interaction. For example, transformation of agricultural activities into economically driven development for sustainable food and nutrition security (**F2**) enabled the development of irrigation plans to boost agricultural growth (**W3**) since the interaction created a positive feedback loop that is beneficial to both sectors. This is because making agriculture more economically attractive (F2) attracts farmers to invest in irrigation (W3), which in turn boosts agricultural growth, leading to a more secure and sustainable food supply that benefits both farmers and entire society within the basin. Clean and reliable energy provision can be used in pumping water for irrigation in agricultural fields and to supply water to urban areas. For example, Nairobi entirely depends on water supply from Ndakaini dam in the TRB. However, there were also negative interactions and trade-offs. This is due to the fact that some energy policies such as reduced national energy intensity by 2.8 % annually to achieve a 30 % reduction in emissions by 2030 require high investment costs that might not be feasible to be achieved by smallholder farmers in the TRB, potentially trading-off against food-related policy objectives.

Food sector policy objectives on implementation of innovative and effective safety measures (F1), transformation of agricultural activities into economically driven development for sustainable food and nutrition security (F2), and integrating tree crops into agricultural production and introduce water-sufficient crop species (F3) had positive interactions in the energy and water sectors, and the 'integrated' policies (N1-N3). This is because food objectives focus on strategies to reduce food insecurity through innovation, smart agriculture, precision agriculture, development of sustainable food and nutrition plans,

	W1	W2	W3	E1	E2	F1	F2	F3	N1	N2	N3
W1		+1	-1	+1	+1	-1	-1	+1	-1	+3	+1
W2	+2		+1	+2	+2	-1	-1	-1	-1	+1	+1
W3	+1	+1		+2	+2	+1	+1	+1	+1	+1	+3
E1	+1	+2	-1		+1	0	0	+1	-1	+1	+2
E2	+1	+1	-1	+1		+1	+1	+1	-1	+1	+1
F1	+1	+1	+1	+1	-1		+1	+2	+1	+1	+2
F2	+1	+2	+1	+1	-1	+2		+2	+1	+1	+3
F3	+1	+1	+1	+1	0	+1	+1		+1	+1	+1
N1	+1	+3	+1	+1	-1	+1	+1	+1		+1	+3
N2	+1	+2	+1	+1	+2	+2	+2	+1	-1		+2
N3	+1	+3	+1	+1	+1	-1	0	+1	-1	+3	

Fig. 3. Results of the scoring matrix of the policy coherence assessment between the 11 main WEF policy objectives identified in Table 2. For objective codes descriptions, see Table 2. A full justification for each policy objective interaction can be found in the Supplementary Information. Green represent synergistic interactions, red negative, and blue neutral interactions.

integrating tree crops into agricultural production and introduce water-sufficient crop species. However, there are number of trade-offs. For example, objectives F1-F3 have mostly negative interactions or conflicts with water sectors polices such as W1 and W2 (five of the six score show −1, with one score being +1, although the interactions with W3 are positive) because the food policies are likely to increase water demand, decrease groundwater quality, and may contribute to greenhouse gas emissions from agricultural activities.

Furthermore, there are specific policies that have significant conflicts with each other. For instance, policies W2, W3, and N1 will lead to increased water demand for irrigation, water pollution through application of fertilizers and pesticides, climate change through clearance of trees to bring more land under cultivation, and competition for water resources through poor water allocation across sectors. In addition, food policy objectives (F1) and (F2) yield conflicting results with water policies (W1) and (W2) respectively leading to competing policy priorities. For example, food policy objective on implementing innovative and effective safety measures in line with broader SDGs to reduce food insecurity (F1) conflicts with outlined regulations for acquiring, conserving, supervising and using of water resources (W1) because introducing regulations for water acquisition and usage (W1) may reduce the amount of water available for agriculture, leading to low food production and potentially contradicting the policy objective of reducing food insecurity (F1) in TRB.

Consequently, food policy objectives on transformation of agricultural activities into economically driven development for sustainable food and nutrition security (F2) conflicts with water resource management systems across sectors (W2) because transformation of agricultural production to economically driven development (F2) may promote unsustainable water extraction practices, leading to depletion of available water resources (W2) leading to a long-term negative consequences on water availability and allocation for all sectors such as energy.

Therefore, these policies may need reconsideration as to how, when, and where they are implemented in order to minimise these trade-offs in the TRB.

3.2. The nexus critical objectives

Based on the interactions described, nexus critical objectives (NCOs) were determined. An NCO is a policy goal that analysis shows is most relevant to the studied problems, showing a high number of connections between the main policy objectives (Munaretto and Witmer, 2017). The selection of NCOs was done by selecting policy objectives from the results of the coherence assessment that showed the highest number of interactions during pairwise comparison of the main WEF nexus policy objectives across sectors in the TRB. Eight objectives were identified as NCOs with the highest number of synergies and lower trade-offs. The selected NCOs are represented in Table 3, each having 10 interactions, and covering all WEF sectors. The scores are obtained by summing the scores for each affected policy (in the rows) from Fig. 3. For example, the scores for policy W1 from Fig. 3 (reading across the row) are: +1, −1, +1, +1, −1, −1, +1, −1, +3, +1. This gives one indivisible score (+3), five enabling scores (+1), and four constraining scores (-1). These are summed to give six synergies and four trade-offs, for a total of 10 interactions. This scoring is summarised in the first grey column in Table 3. The remaining scores are similarly attained.

The NCOs are: W1, W2, W3 E2, F1, F2, N1 and N2. The aims of these objectives are outlined in Table 2. These policies should be retained, and

Table 3
Summary of interactions from the policy coherence analysis, and identification of the NCOs with 10 total interactions, and highlighted in grey shading.

Policy Interactions	W1	W2	W3	E1	E2	F1	F2	F3	N1	N2	N3
Indivisible (+3)	1	0	1	0	0	0	1	0	2	0	2
Reinforcing (+2)	0	3	2	2	0	2	3	0	0	5	0
Enabling (+1)	5	3	7	4	8	7	5	9	7	4	5
Neutral (0)	0	0	0	2	0	0	0	1	0	0	1
Constraining (-1)	4	4	0	2	2	1	1	0	1	1	2
Counteracting (-2)	0	0	0	0	0	0	0	0	0	0	0
Cancelling (-3)	0	0	0	0	0	0	0	0	0	0	0
Synergies	6	6	10	6	8	9	9	9	9	9	7
Trade-offs	4	4	0	2	2	1	1	0	1	1	2
Total Interactions	**10**	**10**	**10**	8	**10**	**10**	**10**	9	**10**	**10**	9

efforts put in place to ensure these policies are implemented in full and as desired so as to reach cross-sectoral sustainable resources management and development. Based on the interactions (Fig. 3, Table 3, and SI S2), the implementation of the NCOs could have crucial importance in attaining water-food-energy security within the TRB. Collaborative efforts between relevant policymakers and relevant stakeholders both horizontally and vertically in the implementation process may contribute to the preservation of the basin's long-term access to water, food production, and energy resources, and contribute to promoting resource sustainability. It is highlighted that N3, the only TRB-level policy document, although not an NCO (as per this analysis), still showed many (9) interactions with the national-level policies, seven of which are synergistic. This suggests that progress towards N3 goals and objectives can leverage actions taken at higher levels of governance and vice-versa, offering win-win situations and efficiency in policy implementation.

4. Discussion

4.1. Water-energy-food interactions in the Tana River Basin

The water, food, and energy policies in the TRB are intricately linked where policy actions and implementation in one sector directly affects the implementation and attainment of policies in other sectors (Fig. 3, Table 3). For example, hydropower generation is one of the most significant links between water and energy in the TRB where networks of dams such as Masinga, Kiambere, Gitaru, Kamburu, and Kindaruma utilize the flow in the Tana River and its tributaries to generate electricity at a capacity of 567 MW (Koei, 2013). Additionally, there are several reservoirs with a capacity of about 2331 million m^3 (Koei, 2013) that help in the provision of water to boost hydropower generation as well as supplying domestic water and industrial water supply within TRB and its environs. This suggests a number of positive interactions between water and energy as illustrated in Table 3. For instance, the provision of reliable, affordable, and clean energy **(E1)** can support economic growth, which can lead to increased water demand for industrial, agricultural, and domestic use. This interaction can create a positive feedback loop, as the increased water demand can lead to the development of new water resources and infrastructure, leading to increasing water demand, which demands increased energy provision. The risk here would be reaching a situation where the feedback loop leads to increasing water demand to above what can be sustainably supplied within the region. The provision of reliable, affordable, and clean energy (**E1)** can also help to improve water resource management systems (**W2)**. Energy is used to power pumps and other equipment that is used to move water around the basin, and to operate desalination plants. This close interdependence between water and energy in the TRB demonstrates a necessity for coherence in terms of policies in these two sectors to ensure sustainable supply and security of both resources. Fig. 3 shows that, generally, supportive coherence between the water and energy sectors is apparent, at least on paper. Water and energy efficiency gains should be mutually met, and care must be taken that water demand especially does not run away to unsustainable levels.

Results show close interactions between water and food in TRB but on a lower scale. According to the National Water Master Plan (2013), agricultural developments in TRB consume 70 % of water withdrawals from water storage facilities and reservoirs within the basin. This implies that all stages in food systems from production to processing and transport, depend on the availability and accessibility of water, forming close links with these policy ambitions. Interactions between pairs of objectives **F1** and **W3, F2** and **W3,** and **F3** and **W3** show synergistic characteristics, where an implementation of food security strategies, such as the adoption of new safety measures or the transformation of agricultural operations, can facilite the formulation of irrigation programs aimed at enhancing food security in the basin whilst potential leading to water savings through irrigation efficiency gains (assuming no expansion of irrigated agricultural lands). The pairwise interaction between objectives **N3** (a TRB-level policy) and **W3** demonstrates a positive interaction because increasing the amount of land that is irrigated helps to meet the Vision 2030, while ensuring water resources availability and accessibility would enable the creation of these local irrigation schemes. This will enhance agricultural production leading to food security within the basin. This is a clear opportunity to meet both national and TRB-level ambitions. The risk is that too much land being irrigated, will lead to unsustainable water demands leading to shortages in other sectors or at critical times of the year. Therefore, close attention should be paid to how much irrigated land is expanded by, and also the type of crops being irrigated.

The energy sector plays a pivotal role in agricultural growth, development and subsequently the realization of food security in line with the Vision 2030 in TRB. Energy is used for pumping water into various irrigation schemes to enhance agricultural development and production, and therefore energy can help enhance agricultural production and food security. However, in other cases energy use can increase food insecurity and make it more difficult to achieve sustainable food production, because, for example, excessive energy use especially from hydroelectric plants can increase water demand from the hydropower reservoir, leaving less water for other users which may cause strain on water resources for agriculture thereby making it difficult to meet the agricultural need for food security. This is an example of a subtle and indirect example of policy competition resulting from an increase in hydroelectric production (increased water needed to boost hydropower generation indirectly impacting on food production). On the other hand, food processing industries can use by-products (e.g. biowaste) to generate energy that can be re-used for industrial processing or irrigation to enhance agricultural developments. Thus, there are ample opportunities for synergies between energy and food policy objectives, while caution must be taken to avoid trade-offs and competing objectives.

The national government, in collaboration with county governments within the basin, is planning to expand the area under irrigation to about 292,100 ha and construct more irrigation schemes so as to promote food production and enhance food security in line with the Vision 2030 and the realization of SDG 2 This analysis shows that the pairwise comparison between objectives **E1** and **F1** shows a positive interaction where the provision of reliable, affordable, and clean energy can help reduce food insecurity by implementing innovative and effective safety measures that govern food systems from production to processing, helping to meet these national level objectives. It is also important to note strong synergy between **N3** (a TRB level policy) and **W1**, **F2**, and **N1** which are national-level policies, showing that local-level action can support national-level goals and should therefore be promoted. There are likewise positive interactions between **N3** and **E1** and **E2**. Therefore, by achieving energy-related objectives, food-related policy ambitions can be promoted within the TRB. Such synergies between sectors and levels (national and TRB) are critical to recognise, appreciate, and subsequently act upon so as exploit their multiple benefits.

Despite the many positive interactions between water, food, and energy policies, there are several negative interactions (Fig. 3), demonstrating that such analysis is important so as to identify and, if possible, avoid or minimise these effects. For example, the interaction between **W3** and **E1** shows a negative relationship where the development of irrigation plans to boost agricultural growth may conflict with the provision of sufficient reliable, affordable, and clean energy to all, especially if the expansion in irrigation led to a significant increase in energy demand for pumping and pressurisation leading to energy reductions for other users. Similarly, the pairwise interaction between objectives **F1** and **W1,** and between **F2** and **W1,** demonstrate that these two food policies are in conflict with water regulation policy **W1.** This is because an increase in water demand for agriculture may lead to increasing strain on water resources in the basin, consequently affecting water allocation to other sectors such as agriculture and industry, threatening food security**.** In a similar way, food policies **F1** and **F2** are in conflict with water resource management systems policy **W2** because food security objectives are not in accordance with the policy on effective allocation and management of water resources, which might result in water shortages or improper allocation and distribution for all users.

4.2. Policy synergies and trade-offs

A large number of synergies were identified during the policy coherence analysis (Fig. 3). For example, water from River Tana enhances agricultural development through large-scale irrigation schemes such as Hola and Bura which are currently estimated to occupy an area of about 64,425 ha (Baker et al., 2015), promoting food security. There are widespread hydropower developments such as the Seven Fork dams which help in the generation of energy with a total capacity of 567 MW that is supplied throughout the country (Langat et al., 2017). At the same time, renewable sources of energy such as solar are commonly used by small-scale farmers to boost food production. Furthermore, water storage reservoirs such as Masinga, Kamburu and Kiambere store 2331 million m^3 primarily to boost irrigation schemes and hydropower developments in TRB (Koei, 2013). The pairwise comparison between policies **W1** and **E1** is considered synergistic since the provision of regulations for acquiring, conserving, supervising and using water resources (**W1)** enables the provision of reliable, affordable, and clean energy that can support economic growth (**E1)** across all levels since it will guide water storage and usage for energy production through hydropower generation, and should in principle lead to the sustainable and equitable supply of water resources. The **W2** and **E1** pair is synergistic whereby improved water resource management systems reinforce the provision of reliable, affordable, and clean energy that can support economic growth. The synergies are numerous, and occur across all WEF sectors (Table 3). The synergies in the TRB should be analysed in depth by local policy makers to ensure the relevant policies are implemented efficiently and monitored over time to ensure that they achieve their primary aims and that the lowest-hanging synergies are realised over time.

There are trade-offs that must be recognised and mitigated by potentially redesigning how, where, and when policies are formulated and implemented. Policies **F1, F2** and **F3** (note that these are all food-related policies) showed the highest number of conflicts and trade-offs with other sectors. For example, interaction between **F1** and **W2** are conflicting, whereby policy objectives in implementing innovative and effective safety measures in line with the SDGs to reduce food insecurity conflicts with water resource management systems across sectors. This comes about because innovative food production technologies require more water and hence can put strain on available water resources and later interfere with water allocation. Similarly, the interaction between policy objectives **F2** and **W2** is conflicting where the transformation of agricultural activities into economically driven development for sustainable food and nutrition security conflicts with water resource management systems across sectors, potentially through the demand for excessive water volume. This is informed by the fact that agricultural expansion tends to lead to an increased in water use and pollution, hence affecting water quality through fertilizer application. Therefore, food policies and their implementation need to be carefully considered together with other sectoral policy objectives to ensure that the attainment of food security goals does not come at too great an expense of goals in other resources sectors, especially water provision.

4.3. Policy recommendations for the TRB

In the TRB, it has emerged that there is no overarching policy application between the three WEF sectors that can harmonize all objectives – there are always trade-offs to some degree. This research has identified where the main synergies for exploitation lie, but also where there are significant policy trade-offs that should be avoided or minimized where possible. These trade-offs can be better investigated, and may lead to a different approach to policy development and/or the redesign of existing policy so as to minimize these trade-offs. For example, the timing, location, or means of policy implementation could be adjusted in an attempt to minimize trade-offs with other policy goals. From the work and the above discussions, the following concrete recommendations are proposed towards achieving improved policy coherence to enhance more effective multi-sectoral resource management in the TRB:

a) Advocate for reconsideration of WEF nexus policy formulation and monitoring of sectoral targets by involving policy experts from national, county, and basin level within TRB to enhance sectoral trust and minimise resources conflict. This should allow for the potential to reformulate certain policies if these are seen to be overly detrimental to the attainment of other policies. This could apply especially in food related policies which are shown to have the most trade-offs with other sectors;

b) Strengthen institutional cross sectoral collaboration among levels (national, basin, local) involved in water, energy and food policy implementation in TRB, and promote an integrated perspective (Capra and Luisi, 2014) to develop a common framework for holistic decision-making and policy formulation across key sectors;

c) Using the work from this research, task policy makers with better understanding of the synergies between the TRB-level policy "Tana River Basin Climate Adaption Strategy" and national level policies to leverage policy implementation and effectiveness across resources management in the TRB;

d) Organize joint and coordinated workshops bringing together stakeholders from water, food, energy and other sectors across levels of government in TRB to discuss and map out policy interactions to ensure holistic resource management in TRB;

e) Advocate for the formation of a national taskforce encompassing WEF resources experts, community representatives, stakeholders from all levels of governments, and policymakers to discuss, investigate and design tenable solutions to challenges affecting the formulation and implementation of WEF nexus policies within the TRB and other important basins in Kenya;

f) Promote research, WEF nexus training, and capacity building at county and national levels of Government, institutions and communities to educate policymakers, researchers and academics in the added value of an integrated perspective to policy design to enhance understanding of water-energy-food nexus policies and their potential interactions;

g) Fund research in institutions in the TRB and organise WEF resources nexus-based trainings to develop new nexus-based technologies and polices to solve complex WEF resources challenges and enhance resource management and sustainability in the TRB.

5. Conclusions

This study aimed at the assessment of policy coherence in the Water-Energy-Food Nexus with a focus on the Tana River Basin, Kenya. The study analyzed the policy interconnections across the water, energy, and food resource sectors and proposed recommendations for improving policy coherence to lead toward more effective multi-sectoral resource management in the TRB. Based on the results, it is shown that water-related policy objectives have the greatest number of synergies with other resources sectors, meaning that achieving these water goals will help in the attainment of other policy goals. Synergies are found in policies in all resources sectors and should be exploited where possible to achieve multiple policy goals in the most efficient manner. This somewhat unexpected outcome should be viewed very positively, and offers a significant opportunity on which to build integrative policies that support the ambitions across many resources sectors in the TRB and in Kenya. Such design and implementation, if achieved, could be an exemplar across Africa. On the other hand, food-related policy goals, such as the policy objective related to the implementing innovative and effective safety measures in line with broader SDGs to reduce food insecurity **(F1**), and the policy objective on the transformation of agricultural activities into economically driven development for sustainable food and nutrition security **(F2**), showed the highest number of trade-offs, suggesting that these may need to be redesigned (the how, where, when, etc. of implementation).

It is concluded that the application of policy coherence in TRB is still at relatively early stages of development since there is a lack of coordination and integration between the key crucial sectors such as water, food, and energy. This has come about through inefficient means of and processes of policy implementation, monitoring, decision making and actualization to promote development within the basin. From the research, a number of concrete recommendations to promote improved policy coherence in the Tana River Basin are proposed. This research shows significance as being the first multi-resources policy coherence study done in the TRB, and one of the few in Kenya and Africa. As such, it is a foundation on which to build, and aims to inspire similar studies across the continent. Given the abundance of natural resources throughout Africa, and the rapid development of the continent, resources exploitation should be holistically and carefully managed. This research can show one example of how to achieve such aims by better coordinating policy development across resources sectors. It is hoped that this research will lead to more integrated and holistic WEF policy design in the future, not just in Kenya, but across Africa, where synergistic policy goals can be aligned and supported, and where trade-offs and conflicts can be avoided or minimized. As such, the rapid development of the continent could be supported through integrated and coherent policy development aiming to minimise trade-off amongst policy ambitions and prevent the overexploitation of the natural resources base. This work also advances research in the WEF nexus by including the policy dimension, moving away from quantitative modelling efforts. This advance matures the next context, in particular by making research more grounded and offering practical, actionable advice and recommendations for policy and decision making in natural resources management.

CRediT authorship contribution statement

Janez Susnik: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Austine Ochieng Suda:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Graham Jewitt:** Writing – review & editing, Writing – original draft, Supervision. **Sara Masia:** Writing – review & editing, Writing – original draft, Supervision.

Declaration of Competing Interest

The authors declare no competing financial or personal interests related to the submission of this article.

Data Availability

Links to policies in the document and as supplementary material

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103816.

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