DAFNE

A **D**ecision-**A**nalytic **F**ramework to explore the water-energy-food **NE**xus in complex and transboundary water resources systems of fast growing developing countries

INTEGRATED FRAMEWORK OF MODELS FOR SOCIAL, ECONOMIC AND INSTITUTIONAL DEVELOPMENTS

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Abbreviations

CLD:	Causal Loop Diagram
CO2:	Carbon Dioxide
DAF:	Decision Analytic Framework
EAC	East African Community
ES:	Ecosystem Services
FAOSTAT:	Food and Agriculture Organization Statistical Databases
GDP:	Gross Domestic Product
HLPW	High Level Panel on Water
IAEG:	Inter-Agency and Expert Group
ILO:	International Labour Organisation
IO:	Input-Output
MRIO:	Multi-region Input-Output
MS:	Milestone
NB:	Net Benefit
NGO:	Non-Governmental Organisation
NO2:	Nitrogen Dioxide
NSL:	Negotiation Simulation Lab
OWG:	Open Working Group
OTB:	Omo-Turkan Basin
RB:	River Basin
RBO:	River Basin Organisation
SDG:	Sustainable Development Goal
SDGI:	Sustainable Development Goal Indicator
SDSN:	Sustainable Development Solutions Network
TFCA	Trans Frontier Conservation Area
UN:	United Nations
UNESCO:	United Nations Educational, Scientific and Cultural Organization
UNZA:	University of Zambia
WP:	Work Package
WEF:	Water-Energy-Food
WEEF:	Water-Energy-Environment-Food
WRLC:	Water and Land Resource Center
ZRB:	Zambezi River Basin

1. INTRODUCTION

This report presents research conducted as part of the EC-H2020 DAFNE (Decision-Analytic-

Framework to explore the water-energy-food NExus in complex and trans-boundary water resources systems of fast-growing developing countries) project. The project aims to develop a Decision Analytic Framework (DAF) to support stakeholders in effectively managing shared (trans-boundary) water resources. The DAF is informed by a bio-physical modelling component (WP3 – W-E-F Nexus Analysis and Modelling) as well as a socio-anthropologic modelling component (WP4 – Modelling social, economic and institutional developments). This deliverable presents the work conducted within WP4, in terms of the approach towards modelling economic, social and institutional (or governance) developments in the context of the water-energy-food (WEF) nexus; as well as the integration of these models. Grounded in two case study river basins (RB), the Zambezi River Ba-sin (ZRB) and the Omo-Turkana River Basin (OTB), the WP4 models focus on demographic, economic, cultural and social developments, as well as environmental policy and water governance principles.

The socio-anthropologic models of WP4, focus on the behaviours and interactions of the human ac-tor within the ecosystem. These models explore the human responses to environmental stimuli as well as the influence of the human agent on the development of the system. Furthermore, they ex-plore the constraints imposed by policy, regulation and the roles of the institutional structures which govern the interactions of the various actors in the context of the WEF nexus. WP4 is structured around the development of four different types of models:

- Models of Economic Development (Stochastic Game Model)
- Models of Environmental Policy (Model of Legal Principles and Norms)
- Models of Demographic, Cultural and Social Development (Systems Dynamics Model)
- Models and Principles of Water Governance (Law and Policy Classification and Expectation Matrix)

The following sections of this deliverable, present the methodological and conceptual processes undertaken in order to develop the different WP4 models and subsequently integrate them within a unifying framework. The four models are described; outlining the methodological approach adopted in developing each of the models, as well as how the model seeks to address relevant WEF nexus issues. Furthermore, the deliverable builds on the work undertaken in developing Milestone 31 (‘Map of interconnected relationships between WP4 models under WEF-nexus perspective’), and provides an analytical description of the system of the interconnected models produced by WP4. Finally, the deliverable elaborates on the connections (input and feedback) between the WP4 models and both the WEF model, as well as the DAF.

2. MODELLING SOCIAL, ECONOMIC AND INSTITUTIONAL DEVELOPMENTS

As discussed in the previous section, the socio-anthropologic modelling component of the DAFNE project consists of four models which each seek to address various interconnected aspects of the WEF nexus examined by the project; as such each of these models adopts various approaches. While these approaches differ, they are compatible, and allow for the ‘soft integration’ described within section 3. The overall compatibility of the models was an integral part of the development of the methodological approach adopted by each; with the case study areas providing a common basis in terms of focus – each model is based on the two case study areas and adopts the scope of these areas as the system boundary. This section elaborates on the individual WP4 models in order to provide a backdrop for the integration described in section 3.

2.1 MODELS OF ECONOMIC DEVELOPMENT (STOCHASTIC GAME MODEL)

The objective of the economic development model is to describe the economic development of the regions or countries of each case study, describing the use of water and its value to the functioning of the economies (Deliverables 4.1[1] and 4.6[2]). From energy production to sanitation, hygiene, and food production, water plays a crucial role in the development of a nation as a whole. As such, water plays a central role within such a model, given that all parts of an economy utilise water either directly or indirectly.

The model of economic development is formulated as a Stochastic Game Model, produced from a WEF Nexus perspective, and takes into consideration the Total Economic Value of water. As multiple countries share water resources, the likelihood of conflicts over the allocation of water resources increases; particularly under the effects of climate change. The model of economic development aims to identify the optimal economic development pathways and their dependence on water resource availability.

Several studies have analysed the impact of water scarcity on cooperation in water sharing, of which some take into account deterministic water flows and analyse the factors that influence stability of treaties and motivate negotiations (Ambec and Sprumont, 2002; Beard and McDonald, 2007; Ambec and Ehlers, 2008; Janmatt and Ruijs, 2007). Other studies go beyond static measures of water availability. In particular, Dinar (2009) shows that, under increased variability of water supply, a cooperative approach in the form of risk sharing may be preferred over an individual solution. In such circumstances, strategic alliance becomes the basis for a cooperative arrangement to ad-dress the impact of climate change on the stability of water sharing treaties. Using empirical data, Dinar et al. (2010) demonstrate a bell-shaped relationship between water supply variations and treaty cooperation. Ansink and Ruijs (2008) also demonstrate that a decrease in mean flow of a river reduces the stability of an agreement, while an increase in variance may have both positive and negative effects on treaty stability.

Additionally, there is a substantial body of literature on stochastic water resource management from which only few studies exist on the influence of stochastic water resource management on trans-boundary water sharing. Bhaduri et al. (2011) investigated the uncertainty in water resource management in a transboundary water sharing problem and evaluated the scope and sustainability for a potential cooperative agreement between countries. On the other hand, Kim et al. (1989) studied a deterministic renewable groundwater optimal management problem in the face of two-sector linear demands, while Koundouri and Christou (2006) revisited this problem under the presence of a backstop technology.

The model takes into consideration five key sectors as they relate to each of the case study countries, namely:

- agricultural sector
- energy sector
- mining sector
- residential sector
- tourism sector

While the relationship between the agricultural and the energy sectors, and the WEF nexus are clearly discernible, the WEF nexus link with the latter three sectors (mining, residential and tourism) is less so. However, these three sectors are considered as they have a substantial impact on water use within the case study areas; tourism and mining in particular constitute anchor income generating sectors for the local economies of the case study areas. These sectors not only impact the availability of water in the region in terms of consumptive demand for drinking, sanitation (linked to demographic trends of the local populations and seasonal tourist numbers) and industrial processes (as is the case in mining); but also depend on water to provide the natural habitat on

[1] D4.1: Models of the economic development in the Zambezi river basin
[2] D4.6: Models of the economic development in the Omo-Turkana basin

which the local tourism industry relies. In order to provide a more accurate representation than usually provided by abstract models, the sectors associated with each country correspond to a production function, adequately adapted to the corresponding characteristics; such as total employment, pro-duction output of the energy and food sectors, volume of water use, environmental indicators, etc. In particular, the model developed is able to capture the interdependence between two neighbouring, possibly different, economies sharing the same resource. It supports also the principle of sustainable development, in the sense that sustainable strategies for economic development are accommodated given the effects of climate change.

The model captures the influence of water resources on transboundary water management within each of the above sectors, following a multistage dynamic stochastic game approach. In other words, the model examines and characterises the case study countries under two categories; the upstream and downstream countries, which are so characterised due to their physical location and thereby their hierarchical access to the Zambezi river basin and the Omo river basin. Through a cost-benefit analysis, two different scenarios are explored by the model:

- the non-cooperative: where the countries maximize their Net Benefit (NB) curves without considering the externalities caused to their neighbours or the benefits arising from a possible trade, and
- the cooperative scenario: where the countries trade goods between and among them.

Finally, the model determines what course of action is the optimal one for both countries and also the impact on the water levels of lakes Cahora Bassa and Turkana, respectively. The model adopts a stochastic game approach, which captures the influence of stochastic water resources on transboundary water allocation, over multiple sectors of the economy, following a multistage dynamic cooperative game framework. The model illustrates the case of water sharing between an up-stream area (for this purpose considered as Angola, Botswana, Namibia, Zambia, Zimbabwe for the ZRB case and Ethiopia for the OTB case), and a downstream area (considered as Mozambique and Kenya, respectively). The “issue linkage to water sharing” in this case concerns the trade of hydropower produced from the downstream area to the upstream area for the Zambezi case and food exports for the Omo case. Thus, the model is used to investigate whether the issue of water sharing can be linked to hydropower and food exports as the basis for attaining sustained cooperation in water sharing.

2.1.1 Methodological Approach

The methodological approach adopted in developing the economic model can be broken down into two phases:

- Stackelberg “leader-follower” analysis
- Stochastic frontier analysis (to determine production functions)

Stackelberg “leader-follower” analysis

Within the stochastic game approach, the model applies a Stackelberg “leader-follower” analysis. First, the multistage allocation of stochastic water resources between the upstream and the downstream area is modelled under a non-cooperative scenario, where the upstream area chooses how much water to divert unilaterally per sector in order to maximize its own welfare. In this case, the downstream area acts as a “follower”, whose water availability depends on the flow of water diverted by the upstream area. Both areas have two available strategies, myopic and non-myopic; in the myopic case, the area of interest does not consider the benefits coming from the natural resource, i.e. from the river for the upstream area and from the lake for the downstream area, and non-myopic being the other way around. For each strategy, results are compared with respect to the social welfare and optimal water abstraction for each of the two areas, investigating the existence of a ‘Nash equilibrium state’, i.e. where no area benefits by changing strategy while the other one keeps its own unchanged.

Next, the inter-sectoral water sharing strategy between the upstream and downstream area in a cooperative setting is modelled. In this case, the downstream area offers a discounted price for certain products. In the DAFNE case, considering the focus is on interactions within the WEF-Nexus, the products are hydropower exports and/or food exports. These exports are offered to the up-stream area, in exchange for greater transboundary water flow; this results in a higher water reserve accumulation and sequentially in higher production of hydropower and/or food. A differential Stackelberg "leader–follower" game is utilised to determine the optimal inter-sector water allocation between the upstream and downstream areas. In this 'game', the upstream area represents the leader and applies its strategy first, a priori, knowing that the follower (downstream area) observes its actions and a posteriori responds accordingly. A solution to the follower's problem (maximizing his payoff function) is first derived, and then, using the follower's reaction strategy, the leader's objective function can be maximised.

It is assumed that water resources evolve through time and follow a geometric Brownian motion. However, based on the assumption that the effects of climate change differ from one location to an-other (e.g. upstream vs downstream), the characteristics of the Brownian motion in terms of variance are different between the upstream and the downstream areas. In addition, changes in the pattern of the water abstraction within the riparian countries over time are considered; taking into account the greater variability of water availability caused by climate change. In other words, the model describes water allocation between the upstream and the downstream areas, presenting cases both with and without cooperation in water sharing; while taking into account how uncertainty in water supply affects the water abstraction rates of the countries, and explores the underlying conditions that may influence decision-making on water allocation.

Since all the model coefficients are deterministic functions of time, it is assumed that the respective areas use Markovian perfect strategies. These strategies are decision rules that dictate the optimal action of the respective 'players' (the leader and the follower) in feedback form on the current values of the state variables (upstream level of water resources, level of water stock reserves downstream, etc), which summarize the latest available information of the dynamic system.

Stochastic frontier analysis - Production function approach

A production function is the relationship that describes how inputs like Capital, Labour and Natural Resource Capital are transformed into output. More accurately, the production function is a mathematical equation representing the "maximum" output that can be obtained from any fixed and specific set of production inputs at a certain level of technology. The production of marketed goods requires both man-made input as labour and machinery, as well as land and ecosystem-based processes. Not accounting for this can lead to the criticism that the valuation is exaggerating ecosystem service values. A method which is designed to value indirect use values is the production function approach. Production theory is the study of production or the economic process of producing outputs from the inputs, i.e. a process of combining various material inputs and immaterial inputs (plans, know-how) in order to make something for consumption (the output). Thus, the outcome is considered as the dependent variable and production inputs are regarded as independent variables.

The existence of natural capital is crucial within the economic model in order to produce the economic characterization of water resource in the case study areas. Natural capital refers to the global 'stock' of natural resources, which includes geology, soil, air, water and all living organisms. It is an extension of the economic notion of capital (resources which enable the production of more resources) to goods and services provided by the natural environment. Some natural capital assets provide people with free goods and services, otherwise known as ecosystem services (ES). Two of these (clean water and fertile soil) not only underpin economic activity but make human life possible.

Based on this, the key economic drivers which influence water use and key pressures, can be determined. Additionally, general socio-economic indicators such as income and employment, and environmental indicators related to ecosystem services such as land use, emissions, etc. are identified. These economic drivers need to be accounted for from a dynamic perspective, i.e., to determine how these are likely to evolve over time. The final component of the economic characterisation of water in a region is the application of appropriate methodologies to assess sector-specific water demand. This involves deriving the marginal contribution of water in consumption and production of each sector, the maximum willingness to pay for water and the price of the water per sector, and finally, the production of the demand curve from which the *Social Welfare/Benefit*[3] can be determined.

Data for the statistical analysis was collected from well recognised global datasets data sets from sources such as:

- Food and Agriculture Organization of United Nations (FAOSTAT, AQUASTAT),
- ILO (International LABOR Organization),
- The World Bank data,
- The World Bank Group: Climate Change Knowledge Portal For Development Practitioners and Policy Makers,
- The United Nations Statistics Division,
- UNESCO World Heritage list,
- OpenDataSoft,
- Environment & Climate Change Data Portal

Furthermore, information on each sector was sourced from Input-Output (IO) tables from the Eora multi-region IO (MRIO) table database. The MRIO database provides a time series of high-resolution IO tables with matching environmental and social satellite accounts for 187 countries.

The indices used for the estimation of the production functions for each sector (representing the ecosystem services), were constructed from measures of natural resources and landscapes. As each ecosystem service may relate to several resources and landscapes, and each natural resource may provide various ecosystem services, it is only possible to infer the joint value of ecosystem services from those variables. Thus, for each sector common variables which describe the main types of the ecosystem services were chosen (such as raw materials, forest, natural-cultural-mixed heritage sites, biodiversity and habitats, terrestrial protected areas, water quality, annual freshwater withdrawals, and uses, gas emissions (CO2 and NO2) and floods/droughts events). Furthermore, the Sustainable Development Goal Indicators (SDGIs) were considered in the selection of the chosen variables (see section 3.1). Full details on the economic models as well results are available within Deliverables 4.1 and 4.6.

2.1.2 Key findings

In the ZRB, one of the main outcomes of the econometric model was estimating the derived demand for water use of the producers. In particular, in all countries the agricultural sectors are extremely inelastic in water use, i.e. an increase in price would only slightly decrease the water use, revealing so a very intensive dependence between access to water and agricultural products. The agriculture sector in most countries of interest is contributing significantly to the total GDP with 28% of the GDP of Malawi and Mozambique being due to the agriculture. Another outcome was the exit order of the sectors in the event of a drought, revealing so the preferences of the producers for water use. In particular, in Malawi and Mozambique, where energy production is not based in Hydropower, the willingness to pay of the energy producers is not high. However, considering that Malawi and Mozambique, which are two of the four poorest countries in the world, and the population of which is expected to double within the next 30 years, are suffering from unpredictable floods, policy makers will be needed with a view to improving the recognition of the situation.

Within the OTB, the optimal economic scenario in environmental terms is the (Non-myopic, Non-Myopic) combination, where both countries consider the benefits coming from their respective

[3] Social Welfare/Benefit is the total welfare/benefit to society from producing or consuming a good/service. It includes all the private benefits plus any external benefits of production/consumption.

natural resource and the lake runs out of water after 33 years. The worst-case scenario in environmental terms is realised when both countries follow a myopic strategy, where the lake is being depleted in only 15 years and it can be realised in case of lack of trust, lack of institutions bridging the limited disposable information in the countries or even due to limited technical support. The model results present extensive opportunities for trade between Ethiopia and Kenya, which will benefit both countries. There are a number of reasons why an open economy is preferable to a closed one. Firstly, both riparian countries become better off due to comparative advantages of each country concentrating on a specific area of production, i.e. Ethiopia in Hydropower (Energy) and Kenya in Agriculture. Secondly, they make a more valuable use of the river basin with Ethiopia recognising the benefits of trading with Kenya and in so doing, allowing the former have access to augmented quantity of water deriving from the river. Lastly, this collaboration has a positive footprint on the ecosystem surrounding those countries, which is based on the Turkana lake; thereby limiting negative economic and social impacts associated with the destruction of the marine habitat.

2.2 MODELS OF ENVIRONMENTAL POLICY (MODEL OF LEGAL PRINCIPLES AND NORMS)

The adoption of a comprehensive policy framework is critical for transboundary environmental resources given the potential for unclear property rights to result in environmental degradation. There is a particular danger of environmental degradation in Africa's transboundary basins given the importance of the aquatic ecosystems to the provision of a range of services. So far, little work has been done to assess the strength of the policy frameworks in transboundary basins, in order to identify how best to modify them to create an improved policy framework for environmental conservation.

The model of environmental policy developed as part of WP4 is a Model of Legal Principles and Norms, and forms the basis of Deliverable 4.2[4]. The premise of the environmental policy model is that comprehensive, coherent legal and policy coverage to environmental issues is presumed to result in a conducive and effective policy context for environmental sustainability. Conversely, policy limitations, gaps and misalignment across countries and sectors are presumed to result in environmental vulnerability.

As such, a model of environmental policy (based on legal principles and norms) was developed and applied in order to gauge the suitability of existing legal and policy frameworks based on:

- the degree to which they cover key environmental issues
- the degree to which they are harmonized across countries in basins, and
- the degree to which they are coherent across sectors.

2.2.1 Methodological approach

DAFNE and IWMI resources were used to identify and compile literature on environmental issues within the Omo-Turkana and Zambezi Basin. Review of this literature led to identification of several major environmental concerns in the Zambezi Basin. While the order of importance of environmental issues did not necessarily match across the two basins, the main environmental issues were largely the same. Five key environmental issues for investigation were used for the focus of the work: fisheries and aquaculture, forests, wetlands, biodiversity and wildlife.

Environmental law and policy texts from each of the basin countries and basins of the Omo-Turkana and Zambezi formed the primary data utilized. Documents were obtained via the DAFNE database and governmental websites. Online searches were used to supplement those documents that the DAFNE database provided, which was limited to legal documents in the water sector. The extended search targeted legal and policy documents covering each of the non-environmental issues on which this report focused, namely water, energy and agriculture. The laws and policies collected were classified according to a set of basic and technical parameters. The basic

[4] D4.2: Models of environmental policy in the Omo-Turkana and Zambezi river basins

parameters provide the general information about the legal and policy documents such as the name of the document, year, country, sector, etc. Technical parameters covered a range of more specific elements in the context of each of the five key issues (Table 1).

In order to understand the depth of consideration afforded to each of the environmental issues in the basins, depth of coverage to each issue was examined. For each environmental issue, the first task was to establish whether both a legal and policy framework were in place, Subsequently, depth of coverage to particular elements was evaluated on a graduated spectrum from not mentioned to mentioned, to partly to fully regulated. Using the information gathered within the previous task, a comparison was conducted on coverage of the environmental issues both within the environmental sectors of all countries in a basin, and at a basin (transboundary) level. The key points of alignment and key points of divergence across each of the basin countries within each environmental sector were identified. Finally, key non-environmental texts were analysed for any mention of the key environmental issues. A search was conducted within each document for reference to: fish and aqua-culture, forest, wetlands; biodiversity; wildlife. Where no specific reference to key environmental is-sues existed, investigation into broad (general) reference to environment was undertaken through potential reference to conservation, preservation, pollution and protection. Frequency of focus on specific key environmental issues, or broad reference to the environment throughout documents were noted, as were relevant provisions identified as a result of each search.

Table 1 – Technical Parameters used in classification of legal and policy documents

Key Issue	**Technical Parameters**
Fish and Aquaculture	Establishment of both a legal and policy framework; the establishment of protected zones; closed fishing seasons; limitations on the number of licenses/permits granted; aquatic biodiversity; aquaculture; limitations of fishing gear; and consideration of traditional use.
Forest	Establishment of a legal and policy framework, definition of forest resources; establishment of forest reserves and protected areas; afforestation; species conservation/biodiversity; and license for use of protected forests and reserves on certain grounds.
Wetlands	Establishment of both a legal and policy framework; protection zones/Ramsar sites; consideration of traditional use and explicit provisions for species conservation/biodiversity
Biodiversity	Establishment of both legal and policy framework; protection zones; maintenance and regulation of flora and fauna; invasive alien species; habitat loss; community management structure.
Wildlife	Measures for safeguarding wildlife; establishment of legal and policy framework; protection zones; protected species/biodiversity; established ‘buffer zone’ and regulation of hunting of protected species/in protected areas under certain conditions.

The premise of the third analytical thrust – focused on the extent to which (and how) environmental issues were reflected in water, energy and agricultural legislation – is that an effective policy context for environmental sustainability builds on institutions in the environmental sector as well as in key sectors that may impact environmental sustainability. The third analytical thrust of the environmental policy model possesses clear links to a policy framework for the WEF nexus, in some ways broadening this to a water-energy-environment-food (WEEF) nexus. As reported above and highlighted below (Table 2), relevant legislation in non-environmental sectors could do more to internalize the environmental impacts they produce in both basins. In the Omo-Turkana, reference to environmental issues in energy and agricultural legislation tends to be general. In the Zambezi, legislation of countries’ water sectors may possess inconsistencies in approaches for certain environmental is-sues such as wetlands. More broadly, specific transboundary guidelines or policy on environmental concerns in both basins is limited.

Table 2 – Consideration of environmental issues in sectoral legislation

	Water	Energy	Agriculture (Food)
Key Messages (Omo-Turkana Basin)	• Treatment of the environment is general • Treatment often centred on reducing harm and pollution	• Coverage of the environment is sparse • Coverage of environment is often in the context of externalities of petroleum exploration	• Coverage of the environment within agricultural documents is notable but general • Irrigation expansion to be subjected to EIAs to help foster sustainability • Coverage is limited but includes fish and aquatic life and forests
Key Messages (Zambezi Basin)	• Fish and aquaculture, forests, and wetlands are reflected in institutions • Biodiversity and wildlife do not receive extensive focus	• Reference to environment is often general, but reasonable emphasis on minimizing pollution • Forests receive some focus; fish and aquaculture, wetlands, biodiversity and wildlife receive little focus	• The importance of the environment to agriculture is generally recognized • Particular emphasis placed on forests • Fish and aquaculture, wetlands, biodiversity, wildlife receive only general focus

While the model of environmental policy does not specifically make use of indicators or variables in the traditional sense, the classified laws and policies were assessed against three criteria:

- Extent of coverage to five identified environmental issues in the two basins
- Degree of institutional alignment within basins
- Congruity between laws and policies in environment vs. non-environmental sectors

Outcomes of model application led to the identification of several areas that are in need of strengthening, which in turn led to a proposal of three policy alternatives aimed at addressing some of these areas as discussed below.

Extent of coverage to environmental issues

The coverage of environmental issues varied across the legal and policy frameworks of countries in the two basins. In the Omo-Turkana, Kenya generally has a more developed institutional framework - applied to the five identified environmental issues – than Ethiopia. Transboundary attempts to address environmental issues are mostly absent at the Omo-Turkana basin level, but the two countries participated in relevant regional frameworks such as the 2006 East African Community (EAC) Protocol on environment and natural resources management and IGAD water policy endeavours. In the Zambezi basin, transboundary environmental policies exist but their depth and coverage are limited. In the Zambezi, coverage of fish, forests and wildlife across the law and policy frameworks of the basin's countries is reasonable to good. Reference to fisheries are the focus of a specific transboundary water law: the 1999 Protocol on Economic and Technical Co-operation between the Government of the Republic of Zambia and the Government of the Republic of Zimbabwe concerning the management and development of fisheries on Lake Kariba and transboundary waters on Zambezi River. Coverage of wetlands and biodiversity is somewhat piecemeal and fragmented.

Consistency of coverage of environmental issues within the two basins

While there were a range of points on which legal and policy frameworks were synchronized among countries in the two basins, unfortunately a number of differences remain. In the Omo-Turkana, suggestions for greater harmonization can be focused on: types of fishing gear that are legal; modalities of licensing for fishing; legislation related to wetland regulation and protection; legislation related to habitat rehabilitation for biodiversity conservation; regulation of invasive species. In the Zambezi, suggestions for better harmonization across countries include: types of fishing gear that are legal; seasons in which fishing is allowed; institutional frameworks for sustainable wetland management; forest-type specific conservation; classification of species depending on their protection and Red List threat status. More broadly, alignment of policy concerning fish (and indeed other environmental concerns) with evidenced realities may have scope for improvement.

Consistency of coverage of environmental issues across sectors

Relevant legislation in non-environmental sectors could do more to internalize the environmental impacts they produce. In the Omo-Turkana, reference to environmental issues in energy and agricultural legislation tends to be general; irrigation expansion is subjected to Environmental Impact Assessments (EIAs), which is positive, but even here environmental concerns need to be considered more in detail. Water sector legislation tends to focus on reducing harm and pollution. Again, environmental and ecosystem functions and services should be covered by legislation more explicitly. In the Zambezi, legislation of countries' water sectors may possess inconsistencies in approaches for certain environmental issues such as wetlands. Further, focus on environmental issues within legislation of the energy and agriculture sectors is often only general; environmental coverage in such sectoral legislation could be more specific.

Efforts were made to ensure that the selection of the criteria was harmonised both with the variables considered by the other WP4 models, as well as the SDGIs (see section 3.1 for more details).

2.2.2 Key findings

The policy review for the Zambezi and Omo-Turkana basin countries resulted in the formulation of environmental policy alternatives. While there are numerous opportunities for policy changes that can contribute to improved environmental outcomes, three environmental policy alternatives were formulated to achieve an effective conservation of the environment, the key ecosystems and the related ecosystem services in the two basins:

- *Formation of Transboundary Frontier Conservation Areas (TFCAs) to govern Lakes Malawi/Nyasa and Turkana.* The spatial coverage of different types of protected areas and their protecting effect on the ranges of fish, amphibians, mammals and birds on the watershed level were examined to identify hotspot areas where species occur that are not covered by different types of protected areas. Lake Malawi/Nyasa and Turkana emerged as at-risk areas, where the level of protection or conservation reflected in policy is not consistent with the importance of fish and other biodiversity found in the environment. We therefore propose a strengthened policy framework through creation of TFCAs for the two lakes that requires transboundary agreements and law enforcement but brings potential benefits in terms of sustained fisheries, capacity building and increased touristic attraction.
- *Implementation of environmental flows for fish sustainability and hyacinth flushing.* Restoring variability of flows as well as the connectivity within river channels are basic requirements in both basins to enable fish to complete their essential behaviours and thus sustain their populations as a food source for humans. The most straightforward policy recommendation to reach this aim is not to build new dams and to remove existing ones. If this is not possible, policies are required that prescribe engineering measures to allow fish migration upstream as well as flow releases mimicking seasonal flooding. Such extensive flood pulses can equally help to minimize negative effects from invasive water hyacinths by flushing them out of the river system.
- *Adoption of a mechanism for environmental conservation in the two basins in the context of basin-wide River Basin Organisations (RBOs)*. This mechanism could be tailored to monitoring, adoption of common standards, and ironing out the policy and legislation inconstancies pointed out above. Further, the mechanism could work to facilitate agreement on or convergence toward priority conservation geographies and value and priority accorded to key environmental issues. The mechanism could also work to enable cross-sectoral dialogues aimed at upstream incorporation of environmental concerns into sectoral planning, to achieve more sustainable outcomes. While the Zambezi may have a 'head start' on adoption of such a mechanism given

its history of cooperation, fewer riparians in the Omo-Turkana may also present an opportunity there.

2.3 MODELS OF DEMOGRAPHIC, CULTURAL AND SOCIAL DEVELOPMENT (SYSTEM DYNAMICS MODEL)

The social models allow identifying links among diverse societal and resource-related factors in both the Omo-Turkana basin and Zambezi basin case studies. Such links should proactively be addressed in Participatory and Integrated Planning to deal with current challenges and reduce negative consequences of future developments in the basins. The social models were developed as System Dynamic Models. This type of model facilitates a relatively robust identification of links and feedbacks within complex social-ecological systems, which are composed of numerous inter-acting components. System dynamic models allow the user to explore how certain trends (e.g., population growth) bring about other direct or indirect developments (e.g. resource-related impacts). These effects may be intended or unintended. In this way, system dynamic models can show how socio-economic phenomena and environmental aspects interact, which represents important information for resource-related decisions in the W-E-F nexus. As a result, demographic development as well as related drivers and responses could be given special consideration. Systems Dynamic Models do not require quantitative data as input. Instead, qualitative data about links in the system of interest are elicited in cooperation with stakeholders. The final models may be used to identify:

- critical issues in the respective social-ecological system
- links between socio-economic and resource-related factors, and
- the influence they have on each other

The models help to identify knowledge gaps requiring further research and support our understanding of where potential competing activities, feedbacks and side effects may be, thus supporting long-term decision-making in the Omo-Turkana and Zambezi basins.

For both DAFNE case studies, a separate social model was developed based on a participatory approach in which stakeholders shared their expertise with DAFNE researchers. The knowledge and perspectives shared by the stakeholders were used to develop the social models and were reported in Deliverable 4.3[5]. In addition, two theses (Masters and Bachelor) were developed as a result of this research, and the social models largely rely on the outcomes presented in these theses (Eikemeier 2017, Sodoge, in review). In the case of the Zambezi model, the participatory research process for the verification of the model took place during the 'Negotiation Simulation Lab' (NSL) workshop hosted by the DAFNE project under WP6 (Synthesis and Pathway to Impact).

2.3.1 Methodological approach

To link the shared expertise of the stakeholders in the basin, a participatory modelling approach was used involving the development of mental maps through interviews. Mental maps represent the view of a person on a certain topic. In the case of the DAFNE social models, the development of a mental map required a 60-minute interview with individual stakeholders, a large sheet of paper and sticky notes. The results of each individual interview were then analysed and combined into one overall model.

The objective of participatory modelling is to identify links between causes and effects as represented in the simple example of the effects of rainfall in Figure 1 below. Two elements are connected with an arrow from the cause to the resulting consequence. The polarity or direction of the effect is specified: a plus '+' indicates that if the cause increases, the consequence will also increase and if the cause decreases, the consequence will decrease. A minus '-' indicates that if the cause in-creases in magnitude, the consequence will decrease. If the cause decreases, the consequence will increase. In the example illustrated in Figure 1, as rainfall increases, soil fertility increases. On the other hand, drought decreases when rainfall increases. This simple example

[5] D4.3: Models of demographic, cultural and social developments in the Omo-Turkana and Zambezi river basins

illustrates the idea behind the development of causal loop diagrams (CLDs). Such causal loop diagrams can be used to gain insights into complex, dynamic and interconnected issues, and to communicate those in-sights (Tip, 2011). The subsequent section demonstrates how CLDs are developed (based on Vennix, 1996).

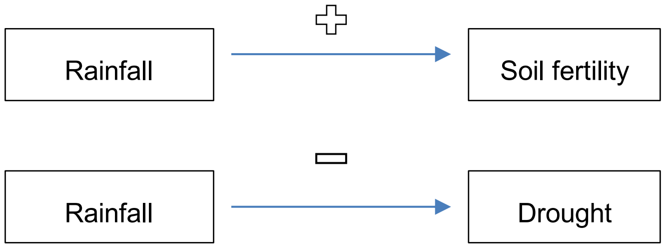

Figure 1 – Example illustrating the idea behind causal loop diagrams

The interviewee is guided by the interviewer throughout the process and receives advice if necessary. Based on the problem variable, the mental map shows causes, consequences, and interlinkages between the elements. The interviewee is asked to define causes of the problem and to connect them with the problem variable. These causes do not necessarily have to influence the problem directly but can also be an indirect cause. The causes are then connected with each other to identify relationships if necessary. The same procedure is conducted for the consequences of the problem. As before, it is up to the interviewee to identify the consequences and to structure their relationships with links. In a final step, the interviewee is free to draw links between the consequences and causes. During the interviews for the Omo-Turkana and Zambezi social models, the interviewees were asked to draw direct and indirect links reflecting their understanding of connections in the W-E-F nexus and then identify the polarity (positive or negative effects). During the modelling pro-cess, the interviewees were free to insert other social, cultural and demographic issues in the dia-gram. The interviews were recorded for subsequent verification of the statements and outcomes. All of the models were digitized and compared with the recorded interview. Then, these digitized models were sent to the interviewees to confirm the outcomes, insert missing information, make corrections, and obtain their final feedback.

For the Zambezi model, stakeholders for the interviews were identified in a joint process with the DAFNE partners responsible for the case study, University of Zambia (UNZA), and selected through a combination of brainstorming and a review of the results of the stakeholder analysis undertaken in Task 6.2 of the project. The resulting stakeholder list included individuals representing the WEF sectors in their line of work for the whole basin and for the Kafue Flats sub-region, which was identified as an area suitable for more in-depth analysis in the project. The selected stakeholders were from governmental and non-governmental organisations and the private sector. Furthermore, web-based research was undertaken to identify additional stakeholders. Based on that information, the preliminary list was reviewed, and a final list was prepared. The stakeholders were all situated in Zambia so that interviews could be undertaken in a reasonably amount of time. Ten stakeholders, representing the three sectors, were interviewed: two representatives of NGOs, two from the energy sector, four from the water sector, one from a government ministry concerned with food, and one representative from the food sector.

For the Omo-Turkana model, criteria for the selection of stakeholders for the interviews included the type of stakeholder organisation, scale, sector, function, interest, expertise, resources, and level of engagement (van Bers, 2018). The final stakeholder selection was then made by the DAFNE partners responsible for the Omo-Turkana case study, WRLC and ACCESS, who also gave their careful consideration to the differing political dynamics in the Omo-Turkana basins. The selection process was underscored by the principle of involving stakeholders from different types of organisations, e.g. non-governmental organisations (NGOs), ministry representatives, private businesses, and independent consulting. Another principle was to involve different knowledge pools among the stakeholders, e.g. representing water, energy or food sectors or focusing on social or environ-mental issues. In order to aggregate the perspectives of the interviewees and arrive at an overall model, individual CLDs were merged. This requires analysing, comparing and subsequently merging the individual diagrams. For a detailed description of this procedure, see Deliverable 4.3.

The variables adopted within the social model (such as population growth, access to water and/or food, displacement, urbanisation and agricultural practices), were selected using a combination of predetermined and issues emergent during the stakeholder workshops. In both cases, as the variables are based on emergent WEF issues, they inherently address each of the three main WEF Nexus domains, which in turn provides a connection to the other WP4 models and the relevant WEF issues they seek to address. As with the other WP4 models, the variables used are mapped onto the SDGIs in a bid to harmonise the analytical framework within WP4 (see section 3.1).

What key findings did we get from this model? At least a few central findings can be provided for to show the result of analysis and implementation of the model.

2.3.2 Key findings

Key elements in the Zambezi model were population growth (selected from five participants as the starting point) and access to water and/or food (chosen by four stakeholders). Key linkages between the elements (identified by more than half of all interviewees) were:

- more deforestation leads to more erosion,
- more erosion causes more sedimentation,
- more water availability leads to more irrigation,
- more irrigation leads to more food production,
- population growth leads to a higher demand for energy,
- a higher demand for energy causes deforestation,
- population growth leads to a higher demand for water,
- more hydropower leads to increasing water availability, and
- more irrigation leads to increasing water availability.

Based on the Omo-Turkana model, differences among the interviews between Kenya and Ethiopia mostly relating to dam construction were found. From the Kenyan perspective, dam construction will lead to more poverty based on a higher scale of water scarcity on the Kenyan side. Ethiopian stakeholders pointed out the positive impact of the dam by regulating floods to provide more constant water availability throughout the downstream system, which would have positive effects on food production and therefore also demographic, cultural and social issues. Furthermore, from the perspective of Kenyan stakeholders, oil exploration from the Kenyan side influenced environmental and social issues, which were mentioned. In the conducted interviews with Kenyan stakeholders the most named links were:

- more oil exploration leads to more oil spills,
- more oil exploration leads to more displacement,
- more oil exploration leads to more land erosion,
- more dam construction leads to more water scarcity, and
- more deforestation leads to more land erosion.

In the Ethiopian model, the links indicated most frequently were:

- more floods lead to more poverty,
- more food production leads to less poverty, and
- more jobs lead to less poverty.

Kenyan and Ethiopian interviews agreed upon most elements influencing issues such as poverty, conflicts or migration. Poverty was named as the most important issue. Furthermore, poverty, migration, and conflicts are all closely linked to each other, and therefore form a kind of centerpiece in the model.

2.4 MODELS AND PRINCIPLES OF WATER GOVERNANCE (LAW AND POLICY CLASSIFICATION MATRIX)

Transboundary watercourses fulfil a number of roles in relation to social and economic development across a number of sectors such as energy and agriculture. They can also present a number of risks such as floods, droughts and environmental challenges. It is therefore challenging for these complex and often competing uses to be balanced, particularly across multiples countries. Governance structures developed through legal, political and organisational institutions aim to manage the nature of the actions occurring within these competing uses in order to ensure that resulting impli-cations are within the boundaries of legal principles derived from international water law.

The water governance model seeks to understand the developments and challenges of applying substantive and procedural legal principles in the context of transboundary watercourses, by presenting a Law and Policy Classification Matrix. The modelling exercise indicates the level of legal expectation with regards to a number of key legal principles across both the Zambezi River Basin (ZRB) and the Omo-Turkana River Basin (OTB). As a result, the model was able to make a number of observations and identify potential pathways for possible reform and integration into the wider DAF.

2.4.1 Methodological Approach

International and national legal and policy documents relating to the WEF nexus were analysed within Milestones 4[6] and 57[7]. The same methodological approach was utilised as in the Environmental Policy Model, whereby an in-depth literature review and qualitative analysis was conducted. Legal and policy documents were obtained from the DAFNE database and government websites and were supplemented by online searches. The search targeted the water sector in particular, but also included National Development Plans and sectoral strategies relating to energy and agriculture.

The collection of legal and policy documents completed within WP2 (Drivers and Indicators of Water-Energy-Food Nexus), under subtasks 2.1.6 and 2.2.4, led to the identification of a number of key legal principles which set out duties and obligations in relation to the use of transboundary water resources. While a list of legal principles cannot be exhaustive due to the wide scope and constant evolution of the law, 13 broad categories of principles relevant to both basins were identified to underpin the governance model. The principles are listed below.

1) Equitable and Reasonable Use[8]
2) No Significant Harm[9]
3) Ecosystem Protection[10]
4) Pollution Prevention[11]
5) Intergenerational Equity[12]
6) Precautionary Principle[13]

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[6] MS4: Identification of water governance structures in the Zambezi river basin

[7] MS57: Identification of water governance structures in the Omo-Turkana basin

[8] *See* UN Convention on the Non-navigational Uses of International Watercourses (UNWC) (36 ILM 700; signed 21 May 1997; in force 17 August 2014). (UNWC), Article 5 and Article 6 with relation to relevant factors to be taken into consideration.

[9] UNWC, Article 7

[10] UNWC, Article 20

[11] Within the Water Governance Model, the principle of pollution prevention is derived from no significant harm. The principle can however also be related to the polluter pays principle which is detailed in Principle 16 of the Rio Declaration on Environment and Development, UN Doc.A/CONF.15/26 (vol.1); 31 ILM 874 (1992)

[12] The principle of intergeneration equity is found within a number of international Conventions, including the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1936 UNTC 269; signed 17 March 1992; in force 06 October 1996) (UNECE Water Convention) (Article 2(5)(c), UN Convention on Biological Diversity (CBD), 1760 U.N.T.S. 79 (in force 29 December 1993), Preamble and the United Nations Framework Convention on Climate Change 1992 31 ILM 849, Article 3(1)

[13] Stipulated in Principle 15 of the UN Conference on Environment and Development, “Rio Declaration on the Environment and Development” (Rio Declaration) UN Doc. A/CONF.151/26 (vol.I); 31 ILM 874 (1992)

7) Environmental Impact Assessment[14]
8) Transboundary Impact Assessment[15]
9) Provision for Establishment of Joint Body/Mechanism[16]
10) Information/Data Exchange[17]
11) Notification[18]
12) Consultation[19]
13) Dispute Settlement[20]

In order to identify the level of legal expectation each document was given two scores: the first on the level of legal force (Table 3), dependent upon the legal status of the document and the second on the language used (Table 4) dependant on whether the key principle was found within the document. Once the scores from Stages 1 and 2 were found, both values were multiplied to give an overall score for that principle within the specific law or policy (Figure 2). It became clear within the research process that the law and policy documents across countries use different wording with similar meaning, therefore a number of alternative wordings were also used to identify if the key principles were present within the document, as presented in Table 5. A detailed elaboration of the model can be found within Deliverable 4.4[21].

The WEF nexus approach within the model is based on the premise of attributing equal importance to all three of its domains. It does not determine the shape of governance arrangements, but rather seeks the formation of a cooperative arrangement. In this sense, a WEF nexus approach is not explicitly found within the key legal principles used within the model, however it can be related to the factors used to determine equitable and reasonable use listed within Article 6 of the United Nations Watercourses Convention which take into consideration inter alia socio-economic need, ecological need and conservation, protection, development, and economy of use of water resources. The integration of the WEF issues as a part of the factors considered by the governance model links it not only the other WP4 models but also the SDGIs (see section 3.1).

Table 3 – Stage 1: Legal Force Index

Legal force of international document	**Legal force of document**	
Absence / no signature	Absence	**0**
Policy under signed treaty	Draft national policy	**2**
Policy under ratified treaty	Policy is in place	**4**
Signature (treaty)	Draft legislation	**6**
Ratification (treaty)	Legislation	**8**

[14] Environmental Impact Assessments are now recognised as part of the customary obligation not to cause significant transboundary harm, as stated in Pulp Mills on the River Uruguay, Argentina v Uruguay, Order, Provisional Measures, ICJ GL No 135, [2006] ICJ Rep 113, (2006) 45 ILM 1025, ICGJ 2 (ICJ 2006), 13th July 2006, International Court of Justice [ICJ], para 204

[15] UNWC, Article 11 requires states to exchange information, consult and if necessary, negotiate the possible effects of planned measures on the condition of an international watercourse.

[16] The UNWC suggests that watercourse states may consider the establishment of joint mechanisms (Article 8.2). Stronger obligations regarding the formation of such institutions are found in the UNECE Article 9.

[17] The obligation to exchange information and data flows from the general obligation to cooperate under Article 8 of the UNWC, more specific provisions relating to the exchange of information are found in Articles 9 and 11.

[18] UNWC, Article 11

[19] UNWC, Article 17

[20] UNWC, Article 33

[21] D4.4: Models and principles of water governance in the Omo-Turkana and Zambezi river basins

Table 4 – Stage 2: Use of Language

Classification	**Rationale**	**Example**	
No provision	Principle is absent		**0**
Preamble	Principle is mentioned only in the Preamble	"Bearing in mind the principle of…"	**1**
Non-binding guidance	Principle is mentioned using guiding language only	"may"	**1.5**
Ambiguous negative obligation	Abstain from violation (vague / ambiguous / no elaboration or guidance)	"shall" "reasonable"	**2**
Unambiguous negative obligation	Abstain from violation (specific / unambiguous / elaboration or guidance given)	"shall" "any" "all"	**2.5**
Indefinite positive obligation	Obligation to take action (actions not prescribed or suggested)	"shall"	**3**
Flexible positive obligation	Obligation to take action (guiding action(s) suggested)	"shall" "consider" "take into account"	**4**
Definite positive obligation	Obligation to take action (imperative action(s) prescribed)	"shall" "requires" "all"	**5**

Table 5 – Word Variations Considered within the Governance Model

PRINCIPLE	**WORD VARIATIONS USED**
Equitable and reasonable use	Equity, reasonable, equal, fair
No harm rule	Adverse impact, impact, harm
Ecosystem protection	Natural resources, ecological, ecosystem
Pollution prevention	Prevent, control, reduce, pollution, pollute
Intergenerational equity	Sustainable, generation, future generations
Precautionary principle	Protect, risk, caution
Environmental impact assessment	EIA, impact, assessment, environment
Transboundary impact assessment	Transboundary, riparian, shared, borders, boundary
Provision for Joint Body Establishment	Joint, shared, commission
Information/data exchange	Information, knowledge, share, shared
Notification	Inform, notify
Consultation	Consult, discuss, liaise
Dispute settlement procedures	Dispute, conflict

2.4.2 Key Findings

The water governance model demonstrated that with within the ZRB a number of comprehensive regional and basin-level legal frameworks are in place, which include a number of the key legal principles analysed. Improvements could however be made regarding coherence of implementation of such principles across basin states at a national level. While regional and basin level frameworks within the OTB were not demonstrated to be as elaborate as the ZRB, the model identified that significant progress is being made towards cooperation within the basin, notably illustrated by the development of regional frameworks (through the Intergovernmental Authority on Development) and the formation of benefit sharing agreements relating to energy.

Legal Language Index		0 Absence	2 Draft policy/ policy under signed treaty	4 Policy in place/ policy under ratified treaty	6 Draft legislation/ signatory to a treaty	8 Appearance in law/ ratified treaty
No provision	0	0	0	0	0	0
Preamble	1	0	2	4	6	8
Non-binding guidance	1.5	0	3	6	9	12
Ambiguous negative obligation	2	0	4	8	12	16
Unambiguous negative obligation	2.5	0	5	10	15	20
Indefinite positive obligation	3	0	6	12	18	24
Flexible positive obligation	4	0	8	16	24	32
Definite positive obligation	5	0	10	20	30	40

LEGEND

Scale of Legal Expectation		Level of Expectation
Value range	Indicator	
0-2	Very Low	Legal framework or policy only mentions the relevant principle but places no further expectation on a state with regard to conduct.
2-10	Low – Medium	Relevant principle included within the framework, but within a manner which does not place strictly binding expectations upon a state. Use of language such as 'may'
10-20	Medium	Level of expectation more specific, describe the steps which should be taken by a state towards the fulfilment of the key principles.
20-30	Medium – High	Places a positive obligation upon a state with regards to conduct. Use of language such as 'shall' and 'requires'
30-40	High	Provisions for specific obligations to take action and provide detail regarding how to do so.

Figure 2 – Stage 3: Legal Force Index – Scoring within Legal Expectation Matrix

3. RELATIONSHIP BETWEEN SOCIAL, ECONOMIC AND INSTITUTIONAL MODELS UNDER A WEF-NEXUS PERSPECTIVE

The integration of the four WP4 models was an issue which had been taken into consideration from the beginning of the project. The process began early on, with the first few WP4 meetings dedicated to gaining an understanding of the various disciplinary perspectives involved within the WP. Each modelling team detailed their intended approach towards developing their respective models. While the economic and social models are distinctive in their foci, the environmental policy and governance models share an overlap in terms of the aspects they address. It was concluded that the two models are complementary; while the environmental model aims to identify extent to which relevant laws and policies of riparian countries in ZRB and OTB take into consideration and address critical environmental issues, and propose ways in which responses to environmental issues can be improved, the governance model focuses on the application of these laws within the context of global and regional frameworks. Furthermore, while the environmental policy model strictly addresses legislation relating to the environment, the governance model considers broader themes to do with how states conduct processes (harmonization of national laws and developmental strategies, approaches and processes) developed to manage water resources. During these early interactions between WP4 partners, fundamental questions such as *“what is understood by the term ‘model’?”* were asked, and the divergence of the responses suggested by the various modelling groups further reinforced the importance of devoting time towards gaining this cross-disciplinary understanding. As the WP4 models vary greatly in approach and methodology, this first step was essential to ensure the resulting models would be complementary; and collectively provide a holistic view of the socio-anthropologic workings of case study areas in the context of the WEF Nexus. In principle, all the different models seek to reflect a particular aspect of human and institutional interactions within the conceptual boundaries of the WEF Nexus as it exists in the case study areas. That said, the fact that each model focuses on a niche aspect of this system, meant that the disciplinary silos created primarily methodology and terminology had to be transcended using a common framework and *lingua franca*. After brainstorming on various potential approaches, it was agreed amongst the WP4 partners that Sustainable Development and the Sustainable Development Goals (SDGs) would serve to provide this unifying element, required to begin the construction of an integration framework that could capably bring together all the WP4 models. As such, three key steps were involved in the integration process:

- The production of a Sustainable Development (SD) Framework to serve as the foundation of the integration process
- Plotting an integration map (Milestone 31) which illustrates the linkages and interconnections be-tween all four models
- Plotting the relationship of WP4 models, the WEF Model and the DAF

3.1 SUSTAINABLE DEVELOPMENT AS A FOUNDATION FOR MODEL INTEGRATION

As earlier stated, the first step involved the production of a SD framework, which would essentially provide the conceptual scaffolding upon which the rest of the model integration process could be constructed. The activity began with defining SD, adopting the widely accepted definition provided by the United Nations World Commission on Environment and Development (1987); i.e. *“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”*. In addition, outputs from several other international initiatives were reviewed in order to develop the underpinning elements and principles of the SD framework; these include:

- Themes of UN High Level Panel on Water (UN-HLPW, 2016)
- Rio Declaration on the Environment and Development 1992 (Reaffirmation of Declaration of UN Conference on the Human Environment, 1972)
- Sustainable Development Goals (SDGs)

- SGD Indicators - Developed by Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs)
- Open Working Group on SDGs (OWG on SDGs) Cross-cutting Issues
- The UN Watercourse Convention

The *underlying principles* of the framework are based on the four themes of the United Nations High Level Panel on Water (UN-HLPW), as well as Principles 1, 3, 7 and 11 of the Rio Declaration on the Environment and Development 1992, as stated below (See Box 1).

Box 1 – Underlying Principles of the WP4 Sustainable Development Framework

UNDERLYING PRINCIPLES OF THE SD FRAMEWORK

1. Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature.
2. The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.
3. States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit to sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command.
4. States shall enact effective environmental legislation. Environmental standards, management objectives and priorities should reflect the environmental and development context to which they apply. Standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries.
5. **Water is everyone's responsibility:** "Water connects public health, food security, liveable cities, energy for all, environmental wellbeing, and climate action. Water and sanitation are necessary for human dignity and economic growth. A "whole-of-government" approach is required to better manage water and deliver water and sanitation services. Similarly, households, farmers, and the private sector are the major users of water, and therefore have the responsibility of water stewardship as well. Learning to better share and manage water lies at the core of a sustainable future, whether at the community, city, river-basin, or transboundary levels."
6. **Sustainable services for all**: "Access to water and sanitation services is critical for poverty eradication, human dignity, livable cities, as well as economic growth and pollution prevention."
7. **Valuing our water right:** "Valuing our water right means reducing pollution and increasing the efficiency of water use. It means building resilience to climate change and water extremes. It means allocating it to areas of highest social, economic, and environmental value, whether through policy or pricing mechanisms."
8. **Investing in water for the long run:** "The water sectors have suffered from insufficient financing and inadequate infrastructure development for decades. To provide growing populations with sufficient access to quality water, sanitation, and irrigation services, flood protection, energy, and water storage, large investments in well-designed multi-purpose and resilient infrastructure is critical – both within and across countries."

- *UN, 1992; UN-HLPW, 2016*

Traditionally, the concept of sustainable development is founded upon the three pillars of sustainability; environment, society and economy (Figure 3), commonly referred to as the '3 Ps'. Taking into account more recent iterations of this representation, such as the '5 Ps' (Figure 4, UN, 2016), the WP4 team adopted a '4 P' characterisation of SD (Figure 5), whereby 'policy' forms a fourth pillar of SD. The 4Ps of SD constitute the fundamental building blocks for the WP4 SD framework, which translate into four key domains namely:

- Social profiles
- Economic characteristics
- Environmental status
- Policy landscape

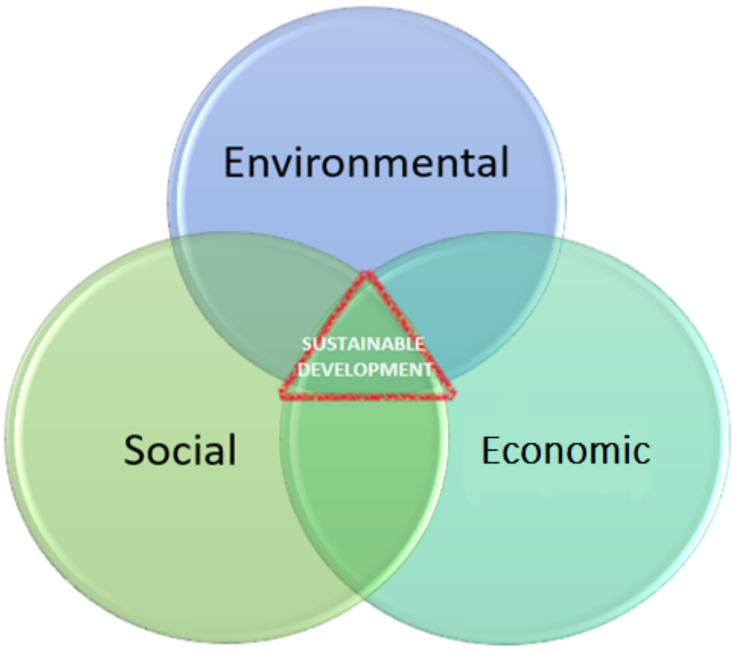

Figure 3 - The three pillars of Sustainable Development

Figure 4 – The '5 Ps' Model of Sustainable Development (Source: UN, 2016)

Figure 5 – Sustainable Development Represented as '4Ps'

These four domains represent key elements of the socio-environmental ecosystem of the case study areas. Cognizant of these key elements, WP4 Tasks 1-4 were scaffolded onto the four domains based on their main areas of focus. This not only served to contextualise each model within the scope of SD, but the relevant domains helped inform the indicators adopted within each of the models. Furthermore, the SD framework was a useful tool in order to crystallise the distinction between the focus and approach of the Environmental Policy and Water governance models.

The indicators and variables adopted within each of the WP4 Tasks are discussed and listed in the next section, and provide a vital component of the respective models, as well as the integration process. The model variables and indicators were utilised as another tether to connect the activities within WP4 to the SD framework, by incorporating the SDGIs into the SD framework. The SDGIs[22] are a set of 232 indicators adopted by the UN in order to monitor global progress on the SDGs[23] (a collection of 17 global goals and 169 targets set out under the UN 2030 Agenda[24], geared towards the advancement of sustainable development across the globe by 2030 – see Figure 6). Given the interconnected nature of the SDGs, all 17 goals bear some level of relevance to the WEF nexus and as such the DAFNE project. However, the most relevant goals to the project are presented in Table 6, based on an analysis of the most relevant SDGIs under each of the WP4 models.

The SDGIs, Sustainable Development Goals, SDG Indicators, along with the OWG on SDG Cross-Cutting Issues (see Box 2) inform the structure and implementation of the SD framework. The full list of SDGIs was reviewed and edited down to a reduced list of SDGIs directly relevant to the tasks of WP4, and were considered by each modelling group during the early stages of the project and taken into account during the data collection process under WP2. The use of the SDG Indicators provides an internationally recognized and comparable set of measures, which is particularly relevant in the context of the transboundary case studies which cut across 10 countries in total (Angola, Botswana, Ethiopia, Kenya, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe). Importantly, modelled scenarios (tied to the activities within WP2) based on the SDG indicators can be benchmarked against the Global SDG Index[25]. Furthermore, there is potential to theoretically validate the accuracy of the models against existing data on the SDG Index Dashboard.

[22] SDG Indicators https://unstats.un.org/sdgs/indicators/indicators-list/
[23] Sustainable Development Goals https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[24] UN 2030 Agenda https://sustainabledevelopment.un.org/post2015/transformingourworld
[25] SDG Index http://sdgindex.org/

Figure 6 – The 17 Sustainable Development Goals (Source: UN, 2016)

Box 2 – Underlying Principles of the WP4 Sustainable Development Framework

OWG ON SDGS CROSS-CUTTING ISSUES

1. Beyond GDP - new measures for development
2. Climate change adaptation and mitigation; disaster risk reduction
3. Food security and nutrition
4. Gender equality
5. Global partnership, including financing for sustainable development
6. Governance
7. Growth and Employment
8. Health
9. Inequalities
10. Industrialization
11. Peace and security, and support for vulnerable states
12. Science, technology, and innovation
13. Sustainable cities and human settlements
14. Sustainable consumption and production
15. Sustainable energy for all
16. Sustainable land use, forests and terrestrial ecosystems
17. Sustainable management of oceans and coastal areas
18. Water and sanitation
19. Wellbeing

\- *SDSN, 2015*

Table 6 – WP4 Model Variables and Indicators in the Context of the SDGs and SDGIs

SDGs and Relevant SDG Indicators		**WP4 Model Relevance**			
SDG	**INDICATORS**	**Econ.**	**Env.**	**Soc.**	**Gov.**
1 NO POVERTY	1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural)				
	1.2.1 Proportion of population living below the national poverty line, by sex and age				
	1.2.2 Proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions				
	1.4.1 Proportion of population living in households with access to basic services				
	1.4.2 Proportion of total adult population with secure tenure rights to land, (a) with legally recognized documentation, and (b) who perceive their rights to land as secure, by sex and type of tenure				
	1.5.2 Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)				
2 ZERO HUNGER	2.1.1 Prevalence of undernourishment				
	2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)				
	2.3.2 Average income of small-scale food producers, by sex and indigenous status				
	2.4.1 Proportion of agricultural area under productive and sustainable agriculture				
	2.5.2 Proportion of local breeds classified as being at risk, not at risk or at unknown level of risk of extinction				
3 GOOD HEALTH AND WELL-BEING	3.1.1 Maternal mortality ratio				
	3.1.2 Proportion of births attended by skilled health personnel				
	3.2.1 Under-5 mortality rate				
	3.2.2 Neonatal mortality rate				
	3.3.1 Number of new HIV infections per 1,000 uninfected population, by sex, age and key populations				
	3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)				

(Table 6 continued)

4 QUALITY EDUCATION	4.5.1 Parity indices (female/male, rural/urban, bottom/top wealth quintile and others such as disability status, indigenous peoples and conflict-affected, as data become available) for all education indicators on this list that can be disaggregated				
	4.6.1 Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex				
	4.7.1 Extent to which (i) global citizenship education and (ii) education for sustainable development, including gender equality and human rights, are mainstreamed at all levels in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment				
	4.a.1 Proportion of schools with access to (a) electricity; (b) the Internet for pedagogical purposes; (c) computers for pedagogical purposes; (d) adapted infrastructure and materials for students with disabilities; (e) basic drinking water; (f) single-sex basic sanitation facilities; and (g) basic handwashing facilities (as per the WASH indicator definitions)				
6 CLEAN WATER AND SANITATION	6.1.1 Proportion of population using safely managed drinking water services				
	6.3.2 Proportion of bodies of water with good ambient water quality				
	6.4.1 Change in water-use efficiency over time				
	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources				
	6.5.1 Degree of integrated water resources management implementation (0–100)				
	6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation				
	6.6.1 Change in the extent of water-related ecosystems over time				
	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management				
7 AFFORDABLE AND CLEAN ENERGY	7.1.1 Proportion of population with access to electricity				
	7.1.2 Proportion of population with primary reliance on clean fuels and technology				
	7.2.1 Renewable energy share in the total final energy consumption				
8 DECENT WORK AND ECONOMIC GROWTH	8.1.1 Annual growth rate of real GDP per capita				
	8.2.1 Annual growth rate of real GDP per employed person				
	8.3.1 Proportion of informal employment in non-agriculture employment, by sex				
	8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP				
	8.5.2 Unemployment rate, by sex, age and persons with disabilities				
	8.9.1 Tourism direct GDP as a proportion of total GDP and in growth rate				
	8.9.2 Proportion of jobs in sustainable tourism industries out of total tourism jobs				

(Table 6 continued)

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	9.2.1 Manufacturing value added as a proportion of GDP and per capita				
	9.2.2 Manufacturing employment as a proportion of total employment				
	9.3.1 Proportion of small-scale industries in total industry value added				
	9.4.1 CO_2 emission per unit of value added				
10 REDUCED INEQUALITIES	10.5.1 Financial Soundness Indicators				
	10.b.1 Total resource flows for development, by recipient and donor countries and type of flow (e.g. official development assistance, foreign direct investment and other flows)				
11 SUSTAINABLE CITIES AND COMMUNITIES	11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing				
	11.3.1 Ratio of land consumption rate to population growth rate				
	11.4.1 Total expenditure (public and private) per capita spent on the preservation, protection and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment) and type of private funding (donations in kind, private non-profit sector and sponsorship)				
13 CLIMATE ACTION	13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other)				
	13.3.2 Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions				
14 LIFE BELOW WATER	14.1.1 Index of coastal eutrophication and floating plastic debris density				
	14.4.1 Proportion of fish stocks within biologically sustainable levels				
	14.b.1 Progress by countries in the degree of application of a legal/regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries				
15 LIFE ON LAND	15.1.1 Forest area as a proportion of total land area	-	-	-	-
	15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type				
	15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits				
	15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020				

(Table 6 continued)

16 PEACE, JUSTICE AND STRONG INSTITUTIONS	16.6.2 Proportion of population satisfied with their last experience of public services				
17 PARTNERSHIPS FOR THE GOALS	17.1.1 Total government revenue as a proportion of GDP, by source				

Legend

SDGI relevant to individual WP4 Model   SDGIs relevant to two WP4 Models   SDGI relevant to three WP4 Models

3.1.1 Integrated Definition of Indicators and Variables

While the identification and definition of the indicators/variables adopted by the different models was conducted independently under each of the WP4 tasks, progress was shared between task teams and there were opportunities to provide input and feedback as the process progressed; thus ensuring that there was some degree of alignment between the indicators adopted by the WP4 models. The indicators and variables adopted by the models were superimposed onto the reduced SDG indicator list, and are presented Table 6.

In total, 59 SDGIs and 15 SDGs were taken into account in some form or another by the four WP4 models. Predictably, it would appear that activities within the different tasks, most strongly correlate to SDG6 (Ensure availability and sustainable management of water and sanitation for all), with a concentration of both the number of relevant SDGIs as well as jointly addressed SDGIs across two or more models.

The general degree of SDGI coverage was wider within the Economic and Social models (which also share a number of jointly addressed SDGIs) and, while the variables adopted within the models do not reflect verbatim the SDGIs, they address similar areas of concern as presented in Table 7.

Table 7 – SDGIs and Relevant WP4 Model Variables Adopted

SDGI	Economic Model Variables	Social Model Variables
6.1.1 Proportion of population using safely managed drinking water services	Population Using Basic Drinking Water Services	• Water quality • Water scarcity • Human health
6.3.2 Proportion of bodies of water with good ambient water quality	Water Quality: Nitrogen Emissions exportable to water bodies from agriculture and household waste water	• Water quality • Water scarcity • Soil fertility • Oil spill
6.4.1 Change in water-use efficiency over time	n/a	• Constant downstream pattern • Irrigation • Water availability • Demand for water
6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	Total Annual Freshwater Withdrawals	• Irrigation
7.1.1 Proportion of population with access to electricity	Percentage of population with access to electricity	• Rural energy access • Electricity access • Energy supply
7.1.2 Proportion of population with primary reliance on clean fuels and technology	n/a	• Renewable energy • Modern energy sources
7.2.1 Renewable energy share in the total final energy consumption	Renewable Electricity Production	• Renewable energy
9.2.2 Manufacturing employment as a proportion of total employment	Employment per sector	• Jobs

By contrast, the Environmental Policy and Governance which do not explicitly make use of variables and indicators in the traditional sense, reflect a more targeted coverage of the SDGIs. Within the Environmental Policy model, the SDGIs are linked with the three main criteria employed in the assessment of the legal and policy documents reviewed. While the Governance model could in principle be linked to all the SDGs, the focus of the model on water-related governance issue meant that the most relevant indicators were linked to five SDGs in particular and a number of corresponding indicators. The links between these two sets of model variables and the SDGIs are reflected in Table 8 and Table 9.

With the all the elements of the SD framework in place established and in place, a schematic was developed (Figure 7), which illustrates the connection between the activities within WP4 (Tasks 4.1 – 4.4), as well as the existing and proposed links with other WPs within the DAFNE project. The SD framework provides the foundation for subsequent integration of the models.

Table 8 – SDGIs and Considerations with the Environmental Policy Model

SDGI	**Consideration within Environmental Policy Model**
6.5.1 Degree of integrated water resources management implementation (0–100)	The first of the three indicators assessed the strength of legal and policy frameworks that covered the environment, which should be a key part of IWRM. Should a country's policy framework neglect to cover a key environmental issue (e.g., wetlands), for example, IWRM implementation would be limited and a score according to this indicator would presumably be less than 100. Ultimately, it is viewed that the first of the three indicators covers one part of the picture of the broader IWRM indicator in the SDG framework.
Proportion of transboundary basin area with an operational arrangement for water cooperation	The second indicator included explicit focus on coverage of environmental issues at a transboundary level. A transboundary water framework is a prerequisite for focus on water-environmental issues. The degree to which transboundary water-environment issues can be addressed in the Omo-Turkana, for example, is no doubt limited by the current absence of a transboundary framework to enable joint solutions to address these issues. And the current absence of such a framework was easily captured by the model indicator.
14.b.1 Progress by countries in the degree of application of a legal/regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries	The first indicator examined presence of legal and policy instruments in countries that are aimed at five key environmental issues. One of such key issues is fish. The strength of legal and policy frameworks to enable sustainable management of fish was assessed.
15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	Biodiversity was treated as one of the key environmental issues in the two basins, and country policy and legislation frameworks were examined to gauge depth of that coverage in our first indicator. Protected areas were considered and in fact one of the policy alternatives developed proposed an expansion of protected areas.
15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits	The model indicators directly respond to this SDGI by assessing the depth of legal and policy coverage of environmental issues at a country level, in the two basins

Table 9 – SDGIs and Considerations within the Water Governance Model

SDGI	Consideration within Water Governance Model
1.1.1 Proportion of population below international poverty line	Development interventions (hydropower, irrigation for agriculture) if managed responsibly can provide economic gains which could contribute to the reduction of poverty
2.4.1 Proportion of agricultural area under productive and sustainable agriculture	Irrigation activities provide the opportunity to work towards achieving improved productive and sustainable agriculture
6.3.2 Proportion of bodies of water with good ambient water quality 6.4.2 Level of water stress: freshwater withdrawal as a proportion of freshwater resources 6.5.1 Degree of integrated water resources management implementation 6.5.2 Proportion of transboundary basin with an operational arrangement for water cooperation 6.6.1 Change in the extent of water-related ecosystems over time 6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	The formation of dam operational rules which take into consideration impacts on water quality can contribute to indicator 6.3.2. Freshwater withdrawal levels can also be optimised through the formation of appropriate operating rules. This will also contribute 6.6.1 by ensuring that ecosystems are not damaged over time. The proportion of transboundary basin with an operational arrangement for water cooperation can be contributed to through the formation of joint mechanisms for cooperation, in line with the key legal principles identified within this model. In addition, local participation is imperative in the formation of such frameworks and mechanisms, the inclusion of which will contribute to 6.b.1.
7.1.1. Proportion of population with access to electricity	Hydropower developments have the potential to contribute to the proportion of the population with access to electricity, both domestically and within riparian states.
15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits	As advocated within this report, benefit sharing arrangements have the potential to provide a framework for the equitable and reasonable use of shared watercourses. The use of which will also contribute to the achievement of 15.6.1.

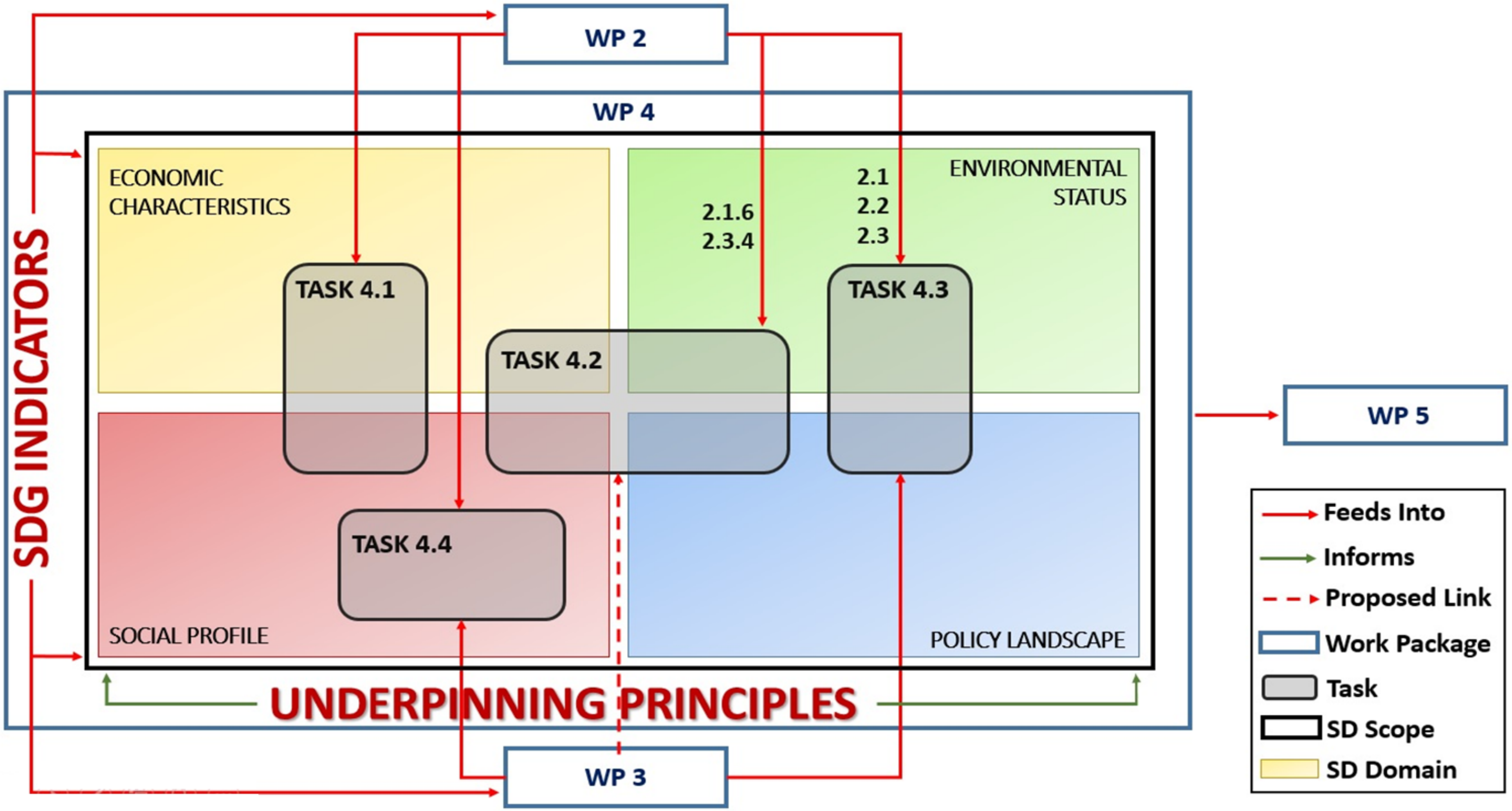

Figure 7 – The WP4 Sustainable Development Framework

3.2 RELATIONSHIPS BETWEEN SOCIAL, ECONOMIC AND INSTITUTIONAL MODELS UNDER WEF-NEXUS PERSPECTIVE

The second phase of the integration process involved the mapping of the relationship between the WP4 for models from the WEF-Nexus perspective (Milestone 31). While the mapping was based on the SD framework developed during the first phase of the integration process; but while the SD framework focuses on the activities within WP4 (i.e. the tasks and the process of developing the models), the integration map focuses on the outcome of the WP4 activities (i.e. the models themselves), illustrating the linkages and interconnections between each of the models as well as their conceptual location in relation to one another. With the mapping focusing on the nature of relationships between several elements, the approach towards its development was strongly rooted in systems thinking and systems modelling methods (Deaton and Winebrake, 2000; Sterman, 2000; Hovmand, 2014). Over a series of meetings between the WP4 task teams, the integration map was developed and refined in order to create the final iteration as presented in Figure 8.

The map comprises of four separate elements namely:

- The SD Framework
- The Case Study Scope
- The SD Domains
- The WP4 models

These four elements are connected by four types of relationships listed below:

- Information
- Nested
- Input
- Feedback

As mentioned earlier, the *SD framework* provides the foundation for the integration mapping. It is connected to the Case Study Scope (and by virtue all the other elements), via an 'information relationship', whereby the SD framework underpins the structure of the mapping. The second element, the *Case Study Scope*, refers to the scope of ZRB and OTB as a Socio-Economic, Legal and Cultural Ecosystem. In keeping with the systems approach, this element provides the conceptual system boundary of the study and hence the mapping. The Case Study Scope has a nested relationship with both the SD Domains and the WP4 models, as both elements lie within the system boundary of the study. The *SD Domains*, are a legacy of the SD Framework, representing the four pillars of sustainable development, and their respective focal areas within the System Scope.

The four *WP4 Models* are grouped into two pairs; socio-economic models (Economic Development Model and Demographic, Cultural and Social Development Model), and institutional models (Environmental Policy Model and Water Governance Model). Each of these pairs are nested within the Economic and Social Domains, and the Environmental and Policy Domains respectively; reflecting the primary domains of activity addressed by the models. A further nested relationship is shared between each of the model pairs; with the Economic Model nested within the Demographic, Cultural and Social Development Model, while the Policy Model is nested within the Water Governance Model. Within the first pair, the *Model of Economic Development* addresses what is considered a niche aspect of the wider *Model of Demographic, Cultural and Social Development*; while in the latter pair, the *Model of Environmental Policy* reflects legal tools which may be adopted to implement the over-arching *Models and Principles of Water Governance*. Furthermore, the nested relationship between the pairs of models also reflects shared variables between each of the two models within the pair; shared demographic indicators as well as shared policy tools and principles.

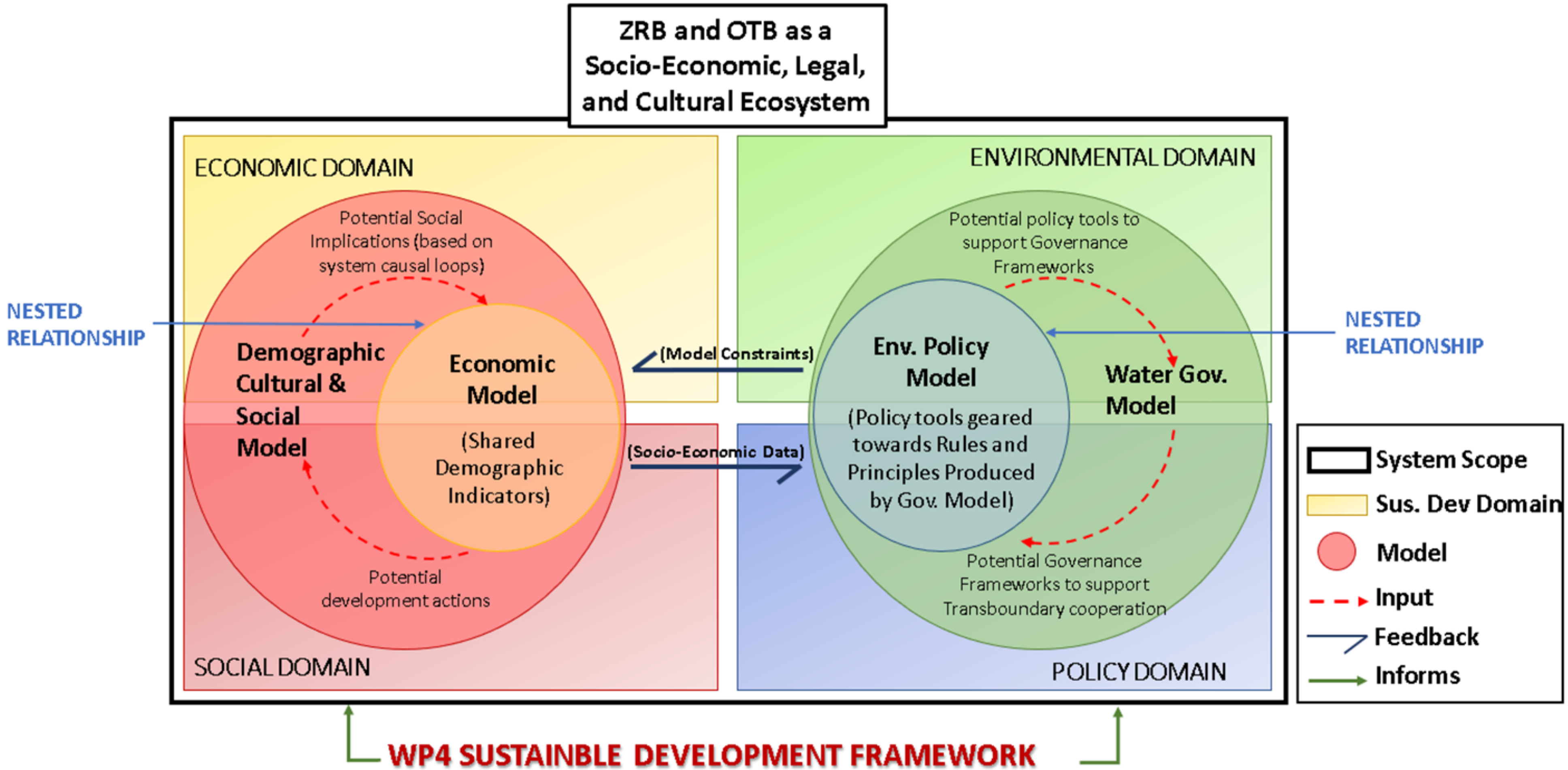

Figure 8 – Map of interconnected relationships between WP4 models under WEF-nexus perspective

Within each of the model pairs, *input relationships* exist in both directions. Between the Socio-economic models, the Economic model generates inputs for the Social model in the form of potential developmental actions; while the Social model in turn produces potential social implications of those actions within the system (based on the causal loops of the systems dynamics model). With respect to the institutional pair of models, the Water Governance model generates potential governance frameworks to support transboundary cooperation as inputs for the Environmental model; which goes on to provide inputs into the Water Governance model in the form of recommendations for potential policy tools to support proposed governance frameworks.

The left-hand (socio-economic) side and the right-hand (institutional) side of the map are connected via *feedback relationships*. These relationships represent the exchange of data and information which serves to fine-tune the operation of the models to better reflect the workings of the system scope, and thereby support the production of more robust model outputs. In this case, the institutional models provide constraints for the application of the socio-economic models; which simultaneously provide socio-economic data outputs (such as the data, findings and trends compiled by the economic, demographic and environmental models which have been utilised and incorporated by the governance model) to support the refinement of the institutional models.

3.3 LINKING SOCIETAL DEVELOPMENTS AND ENVIRONMENTAL RESPONSES: RELATIONSHIPS WITH THE WEF MODEL AND THE DECISION ANALYTIC FRAMEWORK

Once relationships between the different WP4 models had been established, the third and final phase of the integration process called for the elaboration of the links between WP4 models, the WEF Model and the DAF. This final step was fundamental in order to contextualise the WP4 models as the socio-anthropologic modelling component of the project, in relation to bio-physical modelling component (the WEF model), and subsequently the DAF.

The issue of cross-WP model integration was considered from the second year of the project, with a dedicated 'task force' comprised of modellers from all the teams established in order to ensure compatibility between the models, and interfacing not just the work of WPs 3, 4 and 5 but also that of WP2 (within which drivers are identified and scenarios are constructed), and WP6 where the Negotiation Simulation Labs are run. Before the establishment of the modelling task force, an initial sketch of the relationships between all these components was proposed by the WP3 team (Figure 9) which outlined the direction of input from each of the models to another, as expected links with the NSL, drivers and scenarios.

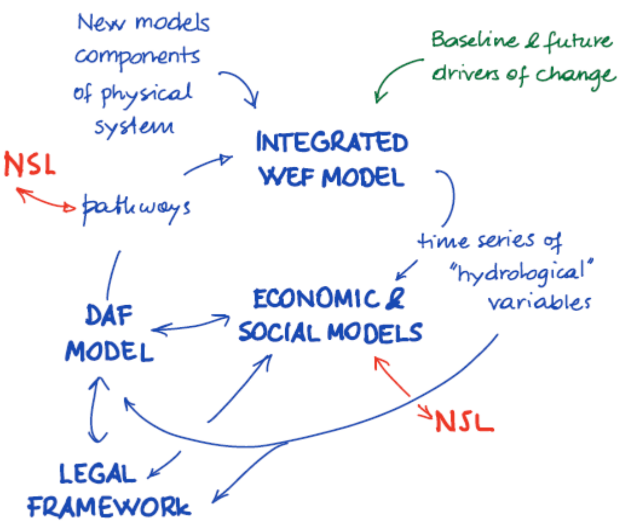

Figure 9 – WP3 Proposed Sketch of DAFNE Model Integration (Source: DAFNE WP3 Team)

Deliberations of the task force produced a more detailed iteration of the cross-WP model integration, which was put forward by the WP5 team (Figure 10). This version was centred around the WEF integrated Model, and provided an intricate breakdown of the models, and focused on the associated tasks and activities that would inform each of the connections between the various elements. Navigating the figure from the bottom upwards, the different subtasks of WP2 provide a list of evaluation indicators and candidate actions. As part of the DAF model, Task 5.1 screens these candidate actions according to qualitative/quantitative indicators derived from the WP4 models, before making a selection of 'design indicators'[26] from the large list of evaluation indicators to be used as objective in the optimization of the pathways. Still in the DAF model, T5.2 adopts the candidate pathways produced by the screening of the actions and the selected WEF design indicators in order to run an optimization, to produce outputs in the form of optimal pathways, i.e. combinations of infrastructural (e.g., construction of new dam) and operational (e.g. reservoir operating policy) actions with timing of implementation. These optimal pathways will be simulated by the WEF integrated model, which will produce the value of some evaluation indicators directly as output of the simulation as well as some trajectories that will be then post-processed by the social-governance-economic models to compute the value of additional evaluation indicators (e.g. indicators not directly implemented in the WEF model, for example about social aspects of the simulated pathways).

Taking these versions (Figure 9 and Figure 10) into consideration, the proposed linkages were incorporated into the previously developed WP4 map, to create a new integration schematic with the WP4 models as the focal point. Figure 11 presents an expanded integration map of the WP4 models, which extends to include the relationship between the WP4 models and the key elements of the DAFNE project including WP2's drivers and scenarios, WP3's WEF model, WP5's DAF and WP6's NSL.

In terms of inputs into the WP4 models, the drivers identified within WP2 (along with the data collected), provide the basis for the development of the WP4 models. The, WEF model also provides preliminary input in the form of hydrological timeseries (which is of particular importance for the development of the economic model). Finally, stakeholder input also from the NSL also supports the identification and selection of variables as part of the process of developing the WP4 models. The NSL also provides an avenue for validation of the model outputs as both preliminary and final model outputs can be fed back to the stakeholders.

The outputs of WP4 models, support the development of the future scenarios described in WP2 (D2.2); as well as provide input to the WEF Model in the form of model constraints which may be applied when running simulations (E.g. policy-based constraints such as limits on abstraction). Similarly, the models outline model constraints for the DAF simulations, but also contribute to the development of the DAF pathways by supporting the identification of candidate actions.

[26] The design indicators represent all the water-energy-food components of the nexus according to the characteristics of the DAF model (which will be coupled with the optimization tools)

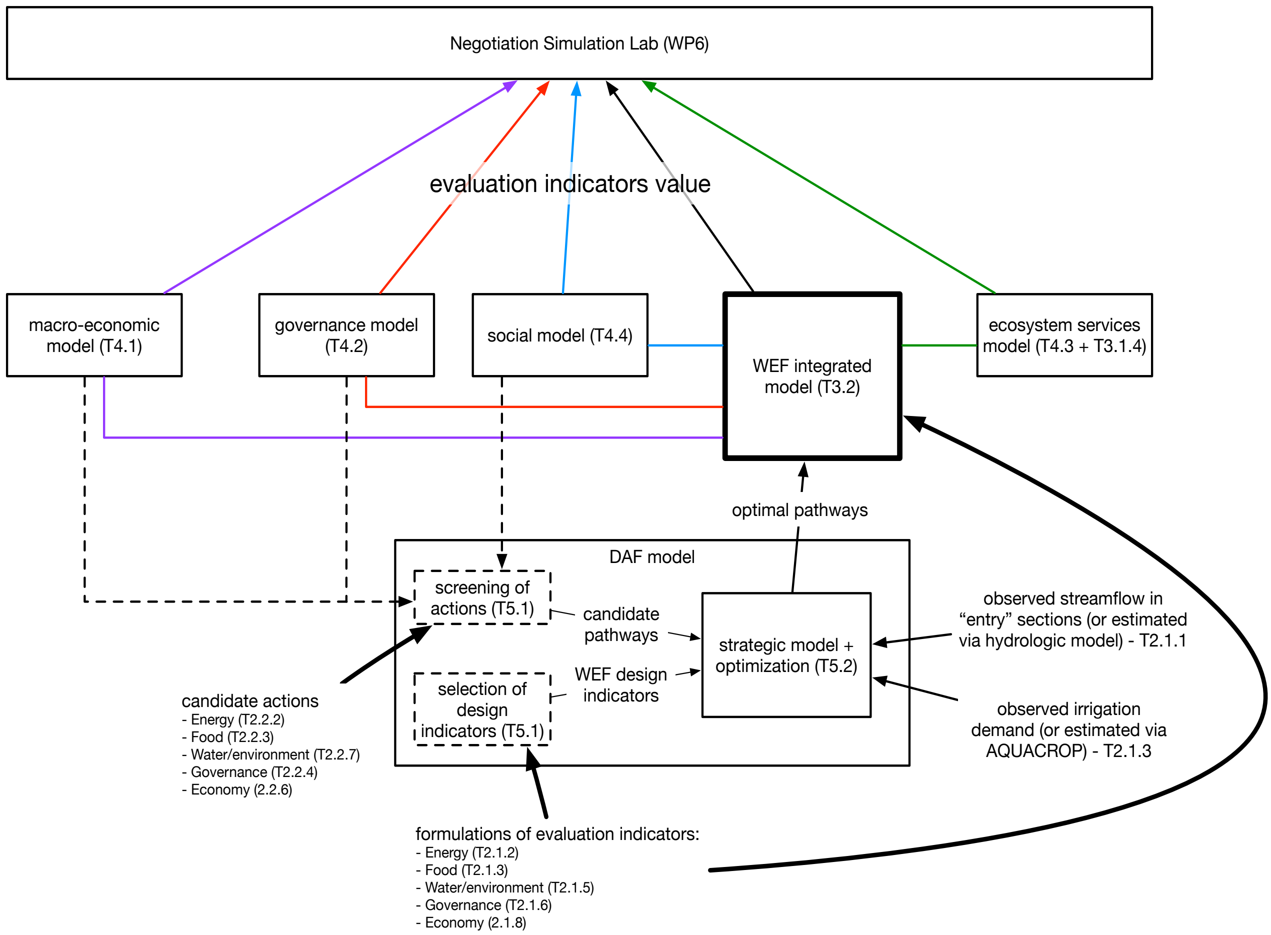

Figure 10 – WP5 Proposed Flow Chart of DAFNE Models elaborating WP Tasks and Activities (Source: DAFNE WP5 Team)

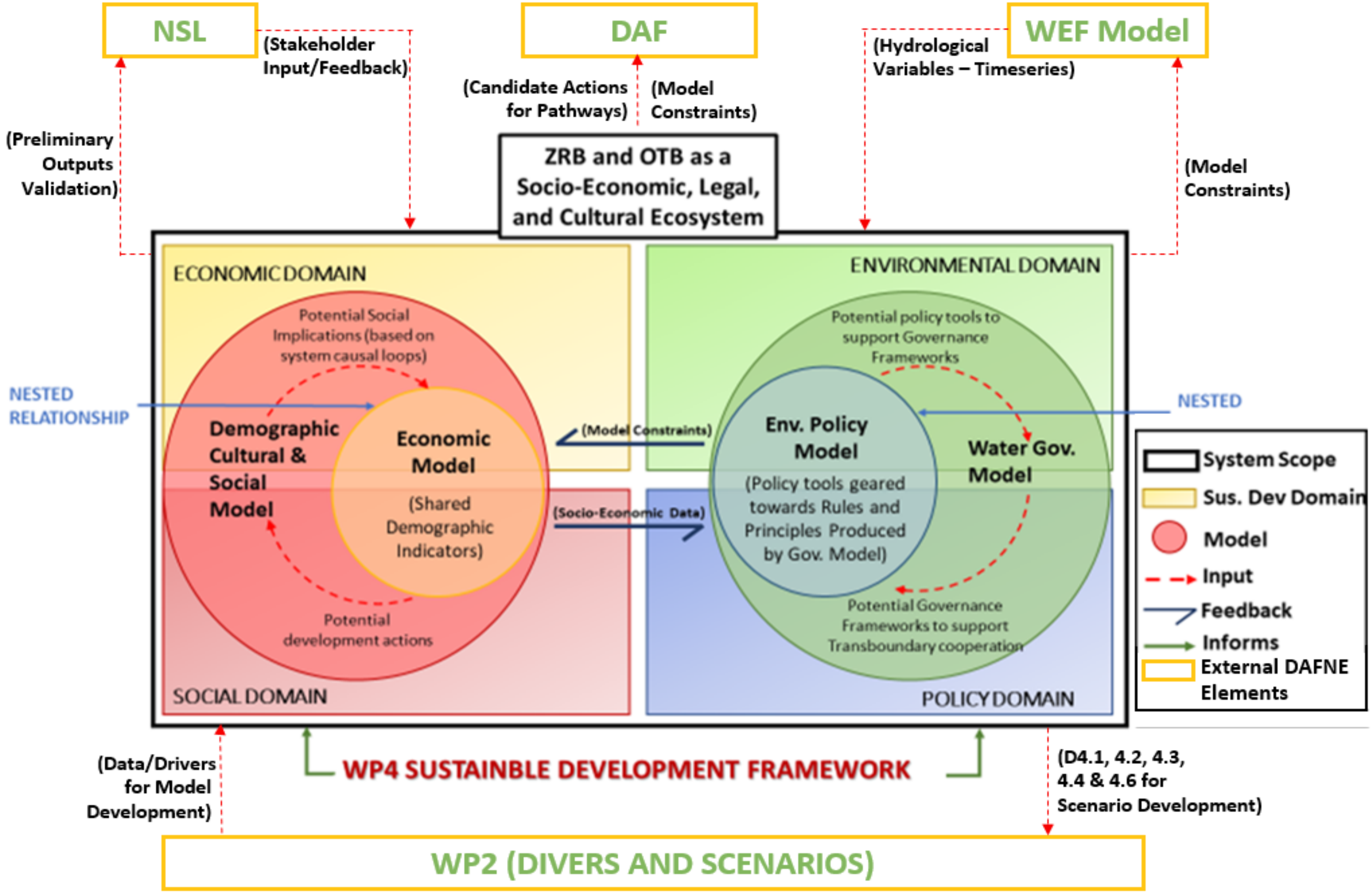

Figure 11 – Mapping of Interconnected Relationship between WP4 Models and other DAFNE Elements (WEF Model, DAF, NSL and WP2)

4. CONCLUSIONS

The integration of the four WP4 models brings together the socio-anthropological aspects of the DAFNE project as described in the preceding chapters of this report. The models seek to provide insight into the human element as part of the wider ecosystem; in terms of socio-cultural and economic activity, the laws and policies that govern these activities as well as the potential impacts and consequences of said activities.

Based on the results of each model as outlined in prior sections of this report, along with the integration approach detailed, it is possible to analyse key WEF issues from multiple perspectives. For example, when the Economic model produces potential actions (e.g. prioritisation of agriculture, or energy production), while the WEF model presents the environmental responses, the Socio-Cultural model produces the potential implications of these actions (e.g. more food production leads to less poverty, or a higher demand for energy causes deforestation). The policy and governance models are then able to present policy tools and governance frameworks that can either support development in line with the proposed actions, or mitigate against potential environmental impacts that could result from a certain course of action. This shows the complementarity and overlapping relations between the governance and environmental models.

While environmental models are useful decision-making tools, considering them in conjunction with socio-economic and policy-based models provides a more holistic overview of the ecosystem. The greatest environmental impacts are arguably as a result of human activity. Furthermore, shifts in the dynamics around the WEF nexus and subsequent trends are equally stimulated by human activity. In the case of the DAFNE DAF, which focuses on the WEF Nexus and as such the dynamics (trade-offs and synergies) between each of the issues which converge at the nexus, obtaining an inclusive perspective is of even greater importance. While each of the models provide an in-depth view into a unique slice of the nexus, incorporating outputs from all the models brings various pieces of the puzzle together, providing a richer picture and making any subsequent decision-making process more robust.

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