Horizon 2020 Societal challenge 5
Climate action, environment, resource
Efficiency and raw materials

D2.5: POLICY RECOMMENDATIONS FOR A RESOURCE-EFFICIENT AND LOW-CARBON EUROPE FROM THE VIEWPOINT OF THE NEXUS BETWEEN WATER, LAND, ENERGY, FOOD AND CLIMATE

LEAD AUTHOR: M. C. H. Witmer

OTHER AUTHORS: F. Swennenhuis, H.C. de Coninck

22/08/2020, revised 16/11/2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement NO 689150 SIM4NEXUS

PROJECT	Sustainable Integrated Management FOR the NEXUS of water-land-food-energy-climate for a resource-efficient Europe (SIM4NEXUS)
PROJECT NUMBER	689150
TYPE OF FUNDING	RIA
DELIVERABLE	D.2.5 Policy recommendations for a resource-efficient and low-carbon Europe from the viewpoint of the nexus between water, land, energy, food and climate
WP NAME/WP NUMBER	Policy analysis and the nexus/ WP2
TASK	T2.5
VERSION	3
DISSEMINATION LEVEL	Public
DATE	22/08/2020, revised 16/11/2020
LEAD BENEFICIARY	PBL Netherlands Environmental Assessment Agency
RESPONSIBLE AUTHOR	Maria Witmer
ESTIMATED WORK EFFORT	15 person-months
AUTHOR(S)	F. Swennenhuis, H.C. de Coninck (Radboud University RU)
ESTIMATED WORK EFFORT FOR EACH CONTRIBUTOR	PBL 5 person-months, RU 10 person months
INTERNAL REVIEWER	Trond Selnes (Wageningen Economic Research, WEcR)

DOCUMENT HISTORY

VERSION	INITIALS/NAME	DATE	COMMENTS-DESCRIPTION OF ACTIONS
1	MW/MARIA WITMER	20-08-2020	DRAFT TO INTERNAL REVIEWER
2	MW/MARIA WITMER	23-08-2020	FINAL REPORT TO SIM4NEXUS PROJECT LEAD, ADJUSTED TO COMMENTS BY INTERNAL REVIEWER
3	MW/MARIA WITMER	16-11-2020	ADJUSTED TO COMMENTS OF REVIEWER

ADDRESSING REVISION COMMENTS NOVEMBER 2020	
COMMENT	RESPONSE
On the disclaimer (pg 16): it claims that the scenarios included in sim4nexus "would hold the increase in the global average temperature to well below 2 °c above pre-industrial level ('2-degree' scenario)". This is disturbing at two levels: first, in the climate community, a 2-degree scenario is absolutely different from a well-below 2-degree scenario; second, it is not clear that a well-below 2-degree scenario is covered in the overall work of SIM4NEXUS.	The name '2-degree scenario' was replaced by 'Energy and Climate scenario' throughout the report (Glossary p. 11-12, Disclaimer p. 18, Sections 3.2.1, 3.2.3.1, 3.2.3.2, 3.2.3.4, 3.2.4.2, 3.2.4.4, 3.3.2). The scenarios were specified in the Glossary (pgs. 11-12) and Disclaimer (pg. 18), and references were added. The application of the 'Energy and Climate scenario' by the SIM4NEXUS cases was specified, namely thematic modelling by the Global and European cases and delivering data to the other cases on demand. Terminology, content, and formulation of all sections in the report about global and European scenarios were again checked by the leads of the global and Europe cases, and adjusted if necessary (sections 3.2.4.2, 3.3.1.1 and 3.3.1.2, in addition to above-mentioned sections).
Pg 31 The following statement on the covid-19 crisis is also disturbing and needs to be revised or removed: "(…) many businesses and jobs depend on unsustainable consumption and production, as the covid-19 crisis has shown". As written, this is an invalid shortcut. The causes of the impact of the covid-19 crisis of jobs and businesses or on the economy in general cannot be summarized in "unsustainable consumption and production". More generally, it would have been great (but of course not required) to develop a bit more how the Covid crisis reinforces the learnings and outcomes from SIM4NEXUS.	Statement was deleted.

Table of Contents

Executive summary

The growth strategy of the European Green Deal on the one hand is ambitious and on the other hand contains many conflicts of interest. The Horizon 2020 project SIM4NEXUS intends to facilitate the detailing and implementation of this strategy from a nexus viewpoint that considers the interlinkages between water, land, energy, food and climate (WLEFC nexus).

Apply 'Upstream thinking'
At strategic level, the wider validity of the 'Upstream thinking' principle should be investigated. This principle, introduced by SIM4NEXUS, stands for prioritizing policies in the order of 1. Change consumption behaviour, 2. Increase resource efficiency, and 3. Meet remaining and potentially growing demand with renewable natural resources and invest in sustainable production methods. SIM4NEXUS modelling confirmed this principle for food, energy and water. It implies fundamental changes in human behaviour, economy and society, as many businesses and jobs within and outside Europe depend on consumption and production within Europe, and people do not easily change behaviour and habits. There will be losers in this transition that need support, but also new opportunities that can be seized. Changing consumption and behaviour to decrease the demand for products has the advantage of both decreasing greenhouse gas emissions and reducing resource use. An implementation of this principle is the proposal in the From Farm to Fork strategy to stimulate a diet change. SIM4NEXUS model calculations show that this is the most synergetic pathway in the WLEFC nexus.

Recognize the value of ecosystems and the landscape
Protect and restore the quantity and quality of ecosystems and the services delivered by water, soil, land and landscapes, will create a cascade of synergies in the WLEFC nexus. Restoration of the degraded agricultural landscape will benefit all WLEFC nexus components. The impact of landscape degradation and dehydration on local climate is underestimated, and occurrence and extent within Europe should be investigated. Landscape restoration can be included in the revised CAP. Nature-based solutions to prevent drought and floods and support climate change mitigation and adaptation are more synergistic in the WLEFC nexus than purely technical solutions.

Make low-carbon and resource efficient pathways coherent
Stimulating resource efficiency and circular economy may increase energy use, and stimulating renewable energy generation may push the use of natural resources. Options to capture synergy between low-carbon and resource efficient pathways must be assessed and seized. Life cycle analyses for both pathways seem to be essential to reach the two goals together.

First and for all, political will and mindset
Political will and mindset are necessary to broaden the scope beyond the usual sectoral perspective and put the long-term interest of a sustainable future above short-term profit. This also applies to the implementation. Rules must be set and enforced, supported by necessary resources. Responsibilities must be clear across sectors and scales. Agree upon financing the policy process and implementation of cross-sectoral and multi-sector policies. Assess cross-sectoral impacts of projects and policies and use this information as an eligibility or criterion for funding or implementation permission. Make databases of portfolios of European funding institutions such as the European Investment Bank more transparent, to facilitate investigations and evaluations of the WLEFC nexus compliance of investments.

Include nexus scope in policies and policy documents
Policies for WLEFC nexus components could refer more to each other and have a more systemic, cross-sectoral view, pointing out linkages, synergy and trade-offs between policies, and higher-level

goals for the whole system. The Renewable Energy Directive (RED) and the Common Agricultural Policy (CAP) cause the most trade-offs in the WLEFC nexus. Use the revisions of REDII and CAP to make them more nexus compliant. Some examples:

- Let cross-compliance and greening conditions in the CAP also count for energy generated from crops that Member States can count towards their national targets when calculating the national share of renewables.
- Trade-offs of large-scale monoculture to the landscape and soil, hydrological cycle, local climate and adaptation capacity, should be addressed in the REDII (bioenergy crops) as well as the CAP.
- Impacts from renewable energy generation on water quantity and quality, as well as impacts on hydrological cycles, must be better addressed and more strictly regulated. The dependency of renewable energy generation on water availability and negative effects of competition for water in case of scarcity, should be assessed and addressed in the context of climate change.
- Support farmers in the transition from livestock to horticulture and arable farming, and stimulate the growth of crops that deliver plant-based proteins.
- Use the CAP to create synergy between water management, agriculture, sustainable production of energy and nature protection and development.

Create broad ownership and commitment

Only with broad ownership and commitment, the ambitious goals of the European Green Deal can be reached. Therefore, invest in a multidisciplinary participative process during the whole policy cycle. Coherent and fair nexus pathways will only be possible in a process with equal power relations between the sectors involved. Potential shared benefits and common interests between sectors must be investigated and communicated in messages that resonate with the audience. Obstacles and objections stemming from conflicting interests and viewpoints must be assessed and addressed. Use influencers to raise public awareness, for example about impacts of their consumption behaviour.

Nexus scope from very start till very end of policy process

Take a nexus approach in policy processes from the very start till the very end. Make nexus and coherence assessment part of inception impact assessments to define the nexus scope and update the scope during the process. Learn from nexus monitoring and evaluation. Build a database of implemented and evaluated nexus policy and lessons learned about synergy and trade-offs. Compare and share experiences with conflicting EU and national regulations, facilitate solutions, and seek for synergy between regulations. Spread out successful nexus implementations and scale them up.

Integrating themes and teams

Integrating themes stimulate a nexus approach. Institutionalize these nexus themes between policy fields and scales, seeking balance between flexibility and enough time to create cross-sectoral expertise and understanding of different viewpoints. Set up cross-sectoral nexus bodies and regional and local nexus hubs to facilitate nexus approaches and the shift from a sectoral to a transversal logic in policy making.

Make data accessible and useful for nexus approach

Better regulate data access and database interoperability at all scales, to coordinate cross-sectoral data exchange, both horizontally and vertically. A framework directive at European scale could support this action. Assign an important role to social sciences to support the policy process, and ensure better understanding of consumer behaviour. Repeatedly facilitate meetings between stakeholders with opposite viewpoints that adhere to different discourses, to create and keep understanding for different interpretations and framings in a context of contested science. Share and check viewpoints repeatedly, as visioning is a continuous process.

Changes with respect to the DoA

No changes to the DoA

Dissemination and uptake

This deliverable is targeted at the European Commission involved with detailing of the European Green Deal, European Parliament, NGOs, representatives and other stakeholders in this process, the general public, national and regional governments in the Member States, participants in the SIM4NEXUS project.

Short summary of results

The growth strategy of the European Green Deal aims at the goal 'Living well within the limits of the planet'. The strategy is ambitious and has many challenges. One of these challenges is achieving policy coherence between policies for water, land, energy, food and climate (WLEFC nexus). The Horizon 2020 project 'SIM4NEXUS', based on twelve case studies and modelling on global, European, national and regional scales, intends to facilitate the detailing and implementation of responses to this challenge. To maximally exploit synergy in the WLEFC nexus, SIM4NEXUS recommends prioritising strategies in the order of 1. Fundamentally change consumer's behaviour in food, energy and water, 2. Increase resource efficiency, and 3. Meet any remaining demand with renewable natural resources and invest in sustainable production methods. Applying this strategy in the food sector includes a change to healthy and more plant-based diets. Another strategy to create coherence in the WLEFC nexus is protecting and restoring ecosystem services and the landscape. Nexus-compliant policy making and implementation require the political will to think across sectors and take a systemic view. This also applies to the Renewable Energy Directive and Common Agricultural Policy. A multidisciplinary participative process with equal power relations between sectors, can raise awareness about the value of system thinking, and shared benefits and common interests in the WLEFC nexus. These insights must be communicated in messages that resonate with the audiences, to create engagement. Finally and crucially, insights from the behavioural sciences can contribute to more effective policy concerning consumer behaviour.

Evidence of accomplishment

Submission of report. Publication of report on SIM4NEXUS website.

Glossary / Acronyms

	EXPLANATION / MEANING
BLUE WATER	Artificially withdrawn groundwater or surface water consumed and evaporated as a result of production. Blue water stands in contrast with 'green' water, which is rainwater or groundwater that is extracted and evaporated in a natural way by vegetation and crops.
INTEGRATED GOVERNANCE	The use of ICT to transform government by making it more accessible, effective, and accountable to its citizenry (World Bank).
POLICY COHERENCE	The quality of a policy to maximally exploit synergy between goals, measures and instruments, and assess trade-offs and conflicts within and between policies, to avoid, mitigate or compensate trade-offs, in this order of priority.
POLICY CYCLE	The cyclic process of policymaking and revision of a policy: problem definition, decision-making about goals, objectives, implementation pathway and instruments, the implementation itself, monitoring and evaluation, back to problem definition.
POLICY IMPACT	Changes in society, economy, governance, environment, brought about by policy output. Impact always starts with changing behaviour of people.
POLICY OUTPUT	Direct result of a policy-making process, for example a plan with goals and objectives, implementation programme and instruments such as laws, levies, education programmes.
POLICY GOVERNANCE	Governance is the sum of the many ways individuals and institutions, public and private, manage their common affairs' (Commission on global governance, 1995). Policy governance concerns all actions that are part of policy making, implementation and evaluation, the way actions are organised with formal and informal arrangements, who is involved, responsibilities and competences
RESOURCE TRILEMMA	Framework introduced by the World Energy Council with three opposing dimensions: security, equity and sustainability. It is introduced to engage with policy makers and energy communities in conversations about navigating the energy transition effectively. The framework can also be applied to other resources such as water and food.
SCENARIOS:	
REFERENCE OR BASELINE SCENARIO	Scenario that aims at representing the current trends of the systems being modelled. It does not include future policies, but only the ones under implementation up to the base year of the analysis, and in the pipeline (i.e. near-term policies or policies that are certain to be implemented in the sectors under analysis). In the SIM4NEXUS modelling, policies resulting from the UNFCCC Paris climate agreement were not included in the baseline. For the thematic modelling in the Global and European SIM4NEXUS cases, the Middle-of-the-road Shared Socio-economic Pathway (SSP2) and Representative Concentration Pathway 6.0 (RCP 6.0) were followed (Riahi et al., 2017; Van Vuuren et al., 2011; Blanco et al., 2020). The Global and European baseline scenarios were downscaled to be applied in several other SIM4NEXUS cases.

TARGET SCENARIO	Scenario that aims at reaching a certain target. The Global case modelled four target scenarios that each aimed at substantial improvement of a WLEFC nexus component towards its policy goals: 1. Water scenario, 2. Land and Biodiversity scenario, 3. Food scenario, 4. Energy and Climate scenario. They also modelled a 'WLEFC nexus target scenario', aiming at improving all nexus components. The European case modelled several variants of an Energy and Climate scenario, exploring alternative mitigation pathways. (Global and Europe cases in Brouwer et al., 2020).
ENERGY AND CLIMATE SCENARIO	Target scenario (see above) used for the thematic modelling in the Global and European SIM4NEXUS cases. The scenario holds the increase in the global average temperature to below 2 °C above pre-industrial level with a probability of 66%. The scenario followed the Middle-of-the-road Shared Socio-economic Pathway (SSP2) and Representative Concentration Pathway 2.6 (RCP 2.6, Riahi et al., 2017; Van Vuuren et al., 2011). Modelling results were delivered to other cases on demand.
SUCCESSFUL WLEFC NEXUS POLICY IMPACT	Changes in society, economy, governance, environment, caused by the policy, that lead to reaching the agreed WLEFC goals effectively, efficiently and sustainably.
SUCCESSFUL NEXUS POLICY/NEXUS COMPLIENT POLICY	A policy that meets three criteria: 1) Policy impact: the policy is effective and efficient to reach the agreed goals for all nexus components and is sustainable. 2) Policy output: problem, goals, implementation and instruments are defined in a transparent way, while addressing policy coherence, maximising synergies within and between sectoral policies and managing conflicts and trade-offs at bio-physical, socio-economic, and governance level. 3) Policy process: the process is fair and transparent, and equally respects interests of stakeholders from different sectors in the nexus.
SUCCESSFUL WLEFC NEXUS POLICY OUTPUT	Policy output in which goals of all sectors involved in the WLEFC nexus, implementation pathway and instruments were defined in a transparent way, while maximising synergy between policies and instruments, and managing conflicts and trade-offs at bio-physical, socio-economic, and governance level. Goals must be relevant for all nexus sectors.
SUCCESSFUL WLEFC NEXUS POLICY-MAKING PROCESS	A policy-making process that is fair and transparent, equally respects interests of all stakeholders involved from the WLEFC sectors and leads to successful policy output and impact. Decisions are made well-informed about WLEFC nexus relations, interdependencies, trade-offs and conflicts.
UPSTREAM THINKING	A strategy for supply chains, that intends to reach most cost-effectivity and synergy between the objectives of resource security, environment protection and human equity by prioritizing policies in the order of 1. change consumption behaviour, 2. increase resource efficiency, and 3. meet remaining and potentially growing demand with renewable natural resources and sustainable production methods.
WLEFC	Water, Land, Energy, Food and Climate
WLEFC NEXUS	The interconnected biophysical and socio-economic system of water, land, energy, agriculture/food, climate (WLEFC) and each sector is equally important and addressed.

WLEFC NEXUS APPROACH	A systematic process of scientific investigation and design of coherent policy goals and instruments that focuses on synergies, conflicts and related trade-offs between water, land, energy, food and climate at bio-physical, socio-economic and governance level.

1 Introduction: context and setting the scene

1.1 Context

The Horizon 2020 project SIM4NEXUS (Sustainable Integrated Management FOR the NEXUS of water-land-food-energy-climate for a resource-efficient Europe) investigated the nexus between water, land, energy, food and climate (WLEFC) with the aim to support the goals of the European Union for smart, sustainable and inclusive growth, including reaching a resource efficient and low-carbon economy. Part of this project was an analysis of coherence between policies relevant for the WLEFC nexus at European, national and regional scales and an inventory of success factors for good governance of the nexus and nexus policy process. This research included an investigation of barriers and gaps that prevent policy implementation (Munaretto et al., 2017; Munaretto et al., 2019; Witmer et al., 2018; Selnes et al., 2019).

In SIM4NEXUS, twelve cases at global, European, national, transboundary and regional scales investigated different aspects of the WLEFC nexus with their own tailor-made research questions (Figure 1). All cases gathered data and used modelling to explore nexus interactions in different scenarios, and the national, regional and transboundary cases organised workshops and interviews with stakeholders to get bottom up information about nexus approaches in practice (Brouwer et al., 2020; Selnes, 2020a). The global case gave context to the European case. The national, regional and transboundary cases showed how European policy is translated and implemented in the Member states and regions. For the present report, the results of the abovementioned studies were combined with an inventory of nexus literature, to develop strategies and recommendations for a resource efficient and low-carbon Europe from a WLEFC nexus viewpoint.

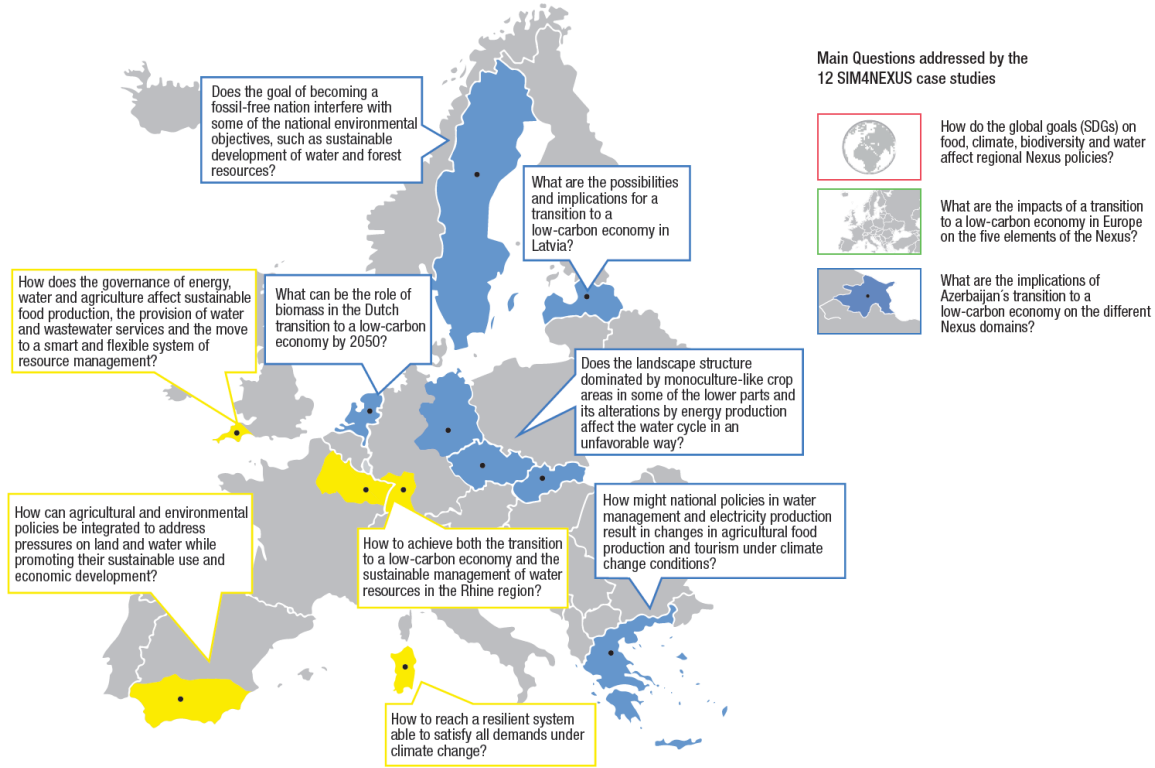

Figure 2. The twelve SIM4NEXUS cases with their main research questions

1.2 Objectives of this report

The objectives of this report are:

- To give recommendations for improving European and national policies relevant to the nexus between water, land, energy, food and climate (WLEFC). These recommendations will look to cover gaps, incoherencies and ambiguities to remove implementation barriers, and promote the idea of systems-thinking across sectors and scales in policy making, which is an essential approach to make policies coherent. Focus will be on interactions between different scales and different nexus components.
- Stemming from these recommendations and from model and case studies, to develop integrated policies, strategies and approaches for a resource efficient and low-carbon Europe.

1.3 WLEFC nexus and governance through a nexus lens

The nexus between water, land, energy, food and climate, the 'WLEFC nexus', consists of components from the natural and human worlds. Water and land are natural resources with their own ecological and spatial values and economic exploitation. Energy and food are interlinked economic sectors that use land and water. Climate is an environmental condition in interaction with the other nexus components (Figure 2). A network of direct and indirect interlinkages between these components and feedback loops creates a complex system. Changes in one component of the nexus may influence other components and the whole system.

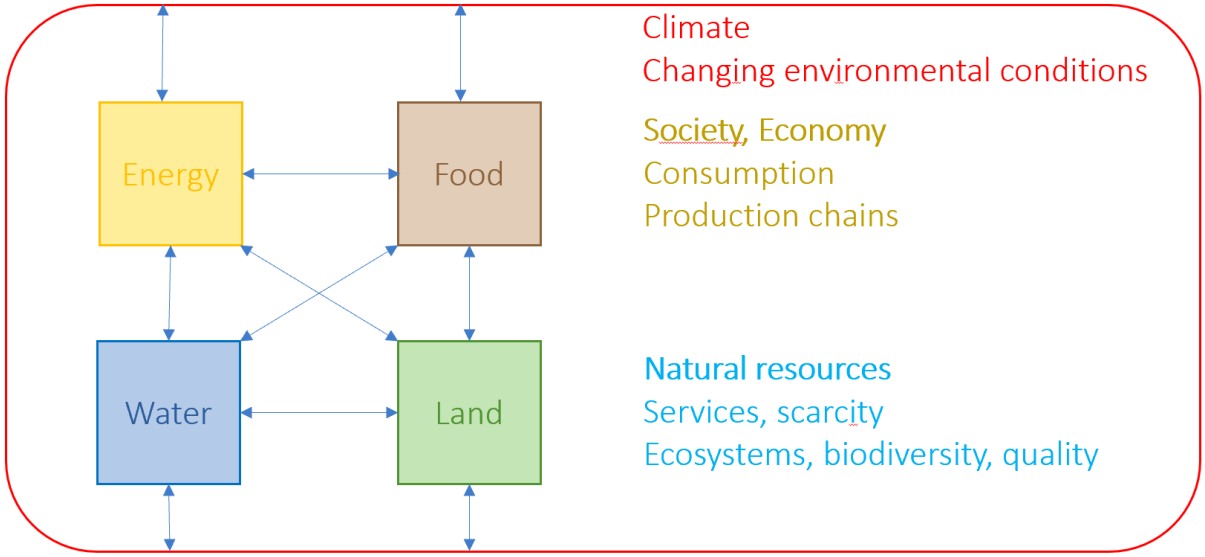

Figure 2. The nexus between water, land, energy, food and climate, the WLEFC nexus. Water and land are natural resources, and energy and food are socioeconomic elements of the nexus. Climate encompasses all, and is also influenced by the other nexus elements.

The WLEFC nexus can be viewed through a biophysical, socioeconomic and governance lens. From a governance perspective, a WLEFC nexus approach is defined as a systematic process of scientific investigation and design of coherent policies, paying attention to synergies, conflicts and trade-offs between water, land, energy, food and climate at biophysical, socioeconomic and governance level. In a nexus approach, the nexus components are considered equally important and are equally addressed

(Munaretto et al., 2017). Political, mental and institutional silo's need to be bridged (Niestroy and Meuleman, 2016).

Newell et al (2019) conducted a quantitative review of the academic literature on the nexus between food, energy and water (1399 publications). They found that scholars in the fields of environmental science predominated, while social science domains were underrepresented. Most papers used quantitative rather than qualitative approaches, especially integrated assessment and systems dynamics modelling. Although spatial scale was generally recognized, explicit consideration of multi-scalar interactions was limited. Issues of institutional structure, governance, equity, resource access, and behaviour were also underdeveloped, according to Newell et al (2019). This report regards multiple scales and policy governance within the WLEFC nexus, and thus fills in some of the noticed literature gaps by Newell et al (2019).

1.4 Coherent policy impact, output and governance

Coherence in policymaking concerns policy impact, output and governance (Figure 3). Impact refers to the changes in the interconnected socioeconomic and biophysical world caused by the policy, and the effectiveness and efficiency of the policy to reach goals for all nexus components. Impact is assessed by observations of reality, monitoring and evaluation ('ex post' and 'ex nunc') and by impact assessments 'ex ante'. Output refers to the products of the policy process, the agreed upon goals, objectives, plans and strategies, programmes and actions, implementation pathways, measures, policy instruments and financing, monitoring and evaluation indicators and programmes.

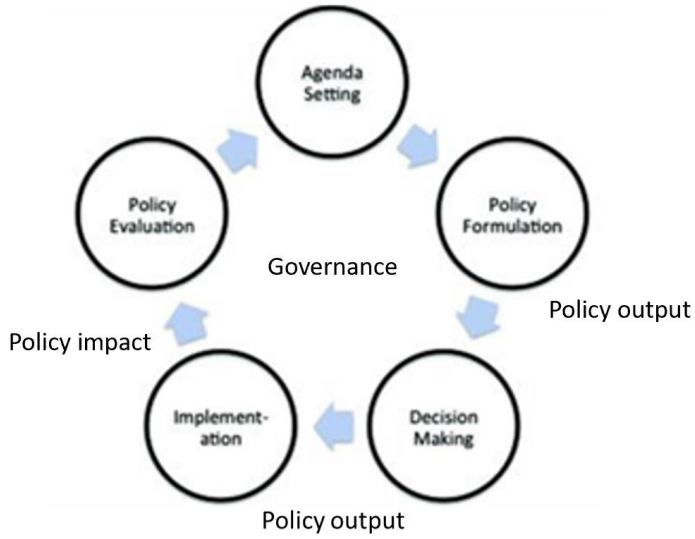

Figure 3. Policy cycle with policy impact, output and governance

In a nexus approach, policy coherence between different policy areas is important. Governance is 'the sum of the many ways individuals and institutions, public and private, manage their common affairs' (Commission on Global Governance, 1995). Policy governance concerns all actions that are part of policy making, implementation and evaluation, the way actions are organised with formal and informal arrangements, who is involved, responsibilities and competences. Governance guides the whole policy cycle, the problem definition in a nexus context, decision-making about goals, objectives, implementation pathways, measures, instruments and financing, the implementation itself, monitoring and evaluation. Impact on economy, society and/or environment is the goal of all policies, to prevent that society goes in undesired directions, and to prevent or restore damage to economy,

society and/or environment. Policy goals and objectives are formulated in terms of policy impact. Policy output and governance are at the service of determining and reaching the desired societal directions and policy impacts. Governance is at the service of successful policy output.

WLEFC nexus policy is defined as successful and coherent if relevant goals are formulated for issues at stake in all sectors involved in the nexus (relevant policy output) and are reached efficiently and sustainably (effective, efficient and sustainable policy impact), with optimal synergy between policies and solutions for conflicts and trade-offs (coherent policy output). Options for synergy must be assessed and exploited, trade-offs must be assessed, prevented or mitigated if possible. If this is impossible, choices between interests must be made well-informed about linkages in the WLEFC nexus, transparently and explicitly, with support and compensation for the losers. This could imply adjusting some of the goals if two goals are cancelling each other and *'progress in one goal makes it impossible to reach another goal and possibly leads to a deteriorating state of the second'* (Nilsson et al., 2012). The organisation and process that lead to these policy choices should be democratic, fair and transparent, and equally respect interests of stakeholders from all WLEFC sectors (science-based, democratic and coherent policy process). This implies stakeholder involvement and exchange between science and policy during the whole process (Witmer et al., 2018).
As competences are differently divided between administrative levels for different WLEFC sectors, and because trade-offs in the nexus cross scales as well as sectors, the governance of the WLEFC nexus is multi-sectoral and multi-scale (Witmer et al., 2018). Political decisions are required at crucial moments, for example when interests between sectors within the WLEFC nexus conflict and targets are to be set.
The EC requires that all its evaluations and fitness checks should assess the effectiveness, efficiency, coherence, relevance and EU added value of policy interventions. Evaluations and fitness checks should also assess the expected and unexpected economic, social and environmental impacts of EU interventions (European Commission, 2020f). From a nexus viewpoint, coherence should especially be investigated cross-sectorally.

The tables in sections 3.2, 4.2 and 5.2 contain criteria for successful policy impact and output, and success factors for policy governance, from a nexus viewpoint. These are based on theoretical literature, for example the criteria used by the European Commission for policy evaluation and fitness checks (European Commission, 2020f), principles of good governance developed by the European Commission (European Commission, 2011), an analysis of eight cases dealing with integrated resource management from different countries worldwide with different management approaches (Svensson, 2018), and information provided by the national, regional and transboundary SIM4NEXUS cases (Witmer et al., 2018; Munaretto et al., 2019; Brouwer and Fournier et al., 2020).

1.5 Structure of the document

This report aims to serve policy of the European Commission. Hence, in ***Chapter 2*** nexus-relevant recent developments and ambitions in European policies are described. The SIM4NEXUS policy analysis targets its strategies and policy recommendations at these developments.

Chapter 3 focuses on the impact of WLEFC policies. Challenges are assessed for coherently reaching the European WLEFC goals described in Chapter 2. Successful policy impact is defined and strategies scetched for effective and efficient policy impact through a WLEFC nexus lens.

Chapter 4 focuses on the policy output of WLEFC policies. Successful policy output is defined, and recommendations are given for coherent and relevant policies through a WLEFC nexus lens. Gaps, incoherencies, ambiguities and barriers are described that are causes of trade-offs and unused synergy options.

Chapter 5 focuses on the governance of WLEFC policies. Challenges are assessed and an overview of success factors given for a nexus-compliant governance and policy process.

In *Chapter 6*, the recommendations, approaches and strategies are summarized for a resource efficient and low-carbon Europe, as well as the added value of a nexus approach for policy and research.

Throughout the report, results from literature beyond the SIM4NEXUS cases and findings are used. The detailed methodology and results of the structured literature review are brought together in the *Annex*. It discusses nexus issues and potential solutions to solve them, as well as the added value of a nexus approach for the management of natural resources, mainly the water-energy-food nexus.

1.6 Disclaimers

SIM4NEXUS thematic modelling, delivering input to the system dynamic models, was finished before December 2019, when the European Green Deal was published. Therefore, it did not include a scenario that would reach zero greenhouse gas emissions in Europe by 2050. The 'Energy and Climate' scenarios that were modelled in the Global and European SIM4NEXUS cases, followed the Middle-of-the-road Shared Socio-economic Pathway (SSP2, O'Neill et al., 2017) and Representative Concentration Pathway 2.6 (RCP 2.6, Van Vuuren et al., 2011). The SIM4NEXUS 'Energy and Climate scenarios' were targeted to hold the increase in the global average temperature to below 2 °C above pre-industrial level, with a probability of 66% (Blanco et al., 2020).
The SIM4NEXUS assessments and recommendations described in this report did not take the effects into account on society, economy, environment, financial and political situation in Europe caused by COVID-19.

2 Upward revision of European ambitions for water, land, energy, food and climate

2.1 New Commission, new ambitions

'Living well, within the limits of our planet', the title of the 7th European Environment Action Programme EAP), summarizes the vision for Europe in 2050. In this future Europe, prosperity and a healthy environment stem from an innovative circular economy as well as sustainable management of natural resources; protection, valuation and restoration of biodiversity enhance society's resilience; low-carbon economic growth is decoupled from resource use (European Commission, 2014). The European Green Deal (EGD), introduced by the new European Commission, continues this vision in describing *'a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts'* (European Commission, 2019a).

The European Green Deal sets ambitions for all components of the WLEFC nexus. These ambitions will be detailed and translated into strategies and legislation in 2020 and 2021 (European Commission, 2019b). In this chapter, recent developments are described in European policies that are relevant for the WLEFC nexus.

2.2 EU ambitions for Energy and Climate are high

2.2.1 Mitigation: climate neutral in 2050

The European new Green Deal sets an ambition for a climate neutral Europe in 2050 and beyond (European Commission, 2019a). To reach this goal, Europe must reduce its greenhouse gas emission with 50-55% in 2030 compared to 1990, instead of the current target of 40%. This implies that the ambitions for renewable energy and energy efficiency must be forced up compared to the recently revised directives (European Union 2018a and 2018b). These are currently to reach at least a 32% share of renewable energy in the EU by 2030 and increase energy efficiency with at least 32,5% in 2030 compared to a reference projection, leading to an annual cumulative energy saving of at least 0.8 % of final energy consumption in Member States in 2021 to 2030. Both the recast of the EU Renewable Energy directive and the amending Directive on Energy Efficiency contain a clause for upwards revision of the targets in 2023. According to the European Green Deal, lasting solutions to climate change require greater attention to nature-based solutions.

2.2.2 Bioenergy, a resource with dilemma's

Biomass and bioenergy touch all WLEFC policy fields with potential synergy and conflicts: energy and climate mitigation and adaptation, agriculture, land use and soil, water quantity and quality, nature and biodiversity, forestry, as well as a biobased and circular economy. Because of all these connections, biomass can be considered an integrating nexus theme. The sustainability of the use of renewable energy from wood and bioenergy crops is disputed. Therefore, the EU's revised Renewable Energy Directive (European Union, 2018a) spends many paragraphs on criteria to minimise negative impacts from their use:

- The revised directive sets a limit of 7% maximum share of fuels made from food and feed crops in road and rail transport in member states and a maximum increase in share of one percent point compared to 2020. Also, limits are set on high ILUC-risk biofuels, bioliquids and biomass fuels with a significant expansion in land with high carbon stock. These limits will affect the amount of these fuels that Member States can count towards their national targets

when calculating the overall national share of renewables and the share of renewables in transport. Member states will still be able to use and import fuels covered by these limits, but they will not be able to include these volumes when calculating the extent to which they have fulfilled their renewable energy targets. These limits consist of a freeze at 2019 levels for the period 2021-2023, and a gradual decrease from the end of 2023 to zero by 2030. The directive also introduces an exemption from these limits for biofuels, bioliquids and biomass fuels certified as low ILUC-risk. According to a recent study, currently only palm oil production partly has a high ILUC risk (European Commission, 2019c).

- Biofuels, bioliquids and biomass fuels should be produced in a sustainable manner and fulfil sustainability and greenhouse gas emissions saving criteria. The production should not encourage the destruction of biodiverse lands and not originate from biodiverse areas. It should not interfere with the designation of areas for nature protection or for the protection of rare, threatened or endangered ecosystems or species. The fuels should be produced consistently with the protection of soil quality and soil organic carbon. These should therefore be monitored by operators or national authorities (European Union, 2018a).
- Criteria are set to minimise the risk of using forest biomass derived from unsustainable production, for example laws must be in place to guarantee regeneration of the forest and maintenance of long-term production capacity.

2.2.3 Higher ambitions for climate change adaptation

According to the European Green Deal, the Commission will adopt a new, more ambitious EU strategy on adaptation to climate change. Strengthening the efforts on climate-proofing, resilience building, prevention and preparedness is crucial. Work on climate adaptation should continue to influence public and private investments, including on nature-based solutions (European Commission, 2019a). Member States and the Union should enhance their adaptive capacity, strengthen resilience and reduce vulnerability to climate change, as provided for in Article 7 of the Paris Agreement, as well as maximise the co-benefits with other environmental policies and legislation. Member States should adopt comprehensive national adaptation strategies and plans (European Commission, 2020d).

2.3 Resource Efficiency roadmap was the first step to a nexus approach

The Roadmap to a Resource Efficient Europe (European Commission, 2011) aimed to build a bridge between institutions related to economic sectors on the one hand and institutions related to protection, preservation and restoration of natural resources on the other hand, with the purpose to promote efficient and sustainable use of natural resources. In the Roadmap, a table shows interlinkages between energy and food on the one hand and fossil and renewable fuels, water, air, land, soil, ecosystems, biodiversity and waste on the other hand. This inventory of interlinkages can be considered a first step to a nexus approach. The issues mentioned are still relevant in the WLEFC nexus: *reduce emissions* to air, water, soil and ecosystems, *efficient use* of energy, water and land and *replace* fossil by renewable energy, *prevent* soil degradation, *preserve and restore* organic matter in the soil, *avoid ecosystem damage* from exploitation of biomass, *restore and preserve* biodiversity and ecosystem services, *reduce food waste* and *increase the re-use* of biodegradable waste for bioenergy and bioproducts. The Roadmap to a resource efficient Europe was followed up in 2015 by the first EU Action Plan for the Circular Economy (European Union, 2015), which has been updated in 2020 (European Commission, 2020a and b) as part of the European Green Deal.

There are fundamental similarities between the European Green Deal and the Roadmap to a Resource Efficient Europe. Both emphasise the need for cross-sectoral cooperation and policy coherence to reach a transition to a low-carbon and resource efficient society, and both stress the vital and undervalued role of ecosystems and their services for the functioning of the economy. Also, both start

from economic growth and do not mention the option of reducing consumption to decrease environmental impacts and stay within planetary boundaries.

2.4 Water: implementation needs a boost

The European Green Deal couples a decrease in water stress to speed up the transition towards a circular economy. It couples decreasing water pollution and consumption of natural resources to a more sustainable food production with less food waste, and a healthier diet. The Green Deal announces that the European Commission will adopt a zero-pollution action plan for air, water and soil in 2021 focusing on prevention of pollution besides cleaning up and remedying it, using a system approach. The natural functions of groundwater and surface water must be restored to preserve and restore biodiversity in fresh waters, and prevent and limit damage from floods (European Commission, 2019a). The Water Framework Directive aims for a good status of all European fresh waters and coastal waters by 2027 (European Union, 2000). By 2019, compliance with the Water Framework Directive objectives had been increasing gradually. However, while a large majority of groundwater bodies had achieved good status, less than half of surface water bodies was in good status (European Commission, 2020d).
With a systemic approach, the European Green Deal builds on the Roadmap to a Resource Efficient Europe. This communication states that sustainable management of water resources requires close coordination with agriculture, transport, regional development and energy policies as well as effective and fair water pricing as required by the Water Framework Directive. Changes in ecosystems, land use, production, consumption and re-use patterns could cost-effectively reduce scarcity and ensure water quality, according to the Roadmap. Impacts of droughts and floods can be minimised with adapted crops, increased water retention in soils and efficient irrigation (European Commission, 2011). Also, the Blueprint to Safeguard Europe's Water Resources adheres to a system approach, linking water policy to land use, the CAP, Cohesion and Structural Funds, renewable energy policy, transport and disaster management. It promotes identification of ecological flows, green infrastructures and natural water retention, Strategic Environmental Assessments for major changes in river morphology such as structures for hydropower, and the development of water efficiency targets for water stressed river basins (European Commission, 2012a).

2.5 More and better-quality forests

According to the European Green Deal, *'the EU's forested area needs to improve, both in quality and quantity, for the EU to reach climate neutrality and a healthy environment. Sustainable re- and afforestation and restoration of degraded forests can increase absorption of CO_2 while improving the resilience of forests and promoting the circular bioeconomy. Building on the 2030 biodiversity strategy, the Commission will prepare a new EU forest strategy covering the whole forest cycle and promoting the many services that forests provide. The new EU forest strategy will have as its key objectives effective afforestation, and forest preservation and restoration in Europe, to help to increase the absorption of CO_2, ... and promote the bioeconomy, in full respect for ecological principles favourable to biodiversity. The national strategic plans under the CAP should incentivise forest managers to preserve, grow and manage forests sustainably.'* (European Commission, 2019a).

According to the new EU Forest Strategy, protection should maintain, enhance and restore forest ecosystems' resilience and multi-functionality, providing environmental services as well as raw materials. Damage on forests should be prevented rather than mitigated and repaired. Member States should maintain and enhance forest cover to ensure soil protection, water quality and quantity regulation by integrating sustainable forestry practices in the Programme of Measures of River Basin Management Plans under the Water Framework Directive and in the Rural Development Programmes under the CAP. They should improve the conservation status of forest species and habitats by fully

implementing EU nature legislation and ensuring that national forest plans contribute to the adequate management of the Natura 2000 network (European Commission, 2013).

2.6 Land use and soil: preserve and increase carbon sinks, prevent degradation and sealing

The priority given to climate change mitigation and adaptation has revived the interest in land use and soil, bringing policy back in current affairs that was formulated in the Resource Efficiency Roadmap (European Commission, 2011).
According to the Regulation on land use, land use change and forestry (LULUCF), Member States should ensure that sinks and reservoirs, including forests, are conserved and enhanced to meet the greenhouse gas emission reduction targets of the Union by 2050. The LULUCF sector can contribute to climate change mitigation by reducing emissions and maintaining and enhancing sinks and carbon stocks. For carbon sequestration to be effective, the long-term stability of carbon pools is essential, as carbon removals from the atmosphere through LULUCF are reversible. The use of wood products with long life cycles is promoted. The Regulation stresses the importance of coherence with policies for agricultural land use, climate change mitigation and adaptation, and with food security and sustainable intensification of food production. Coherence between the Common Agricultural Policy and this Regulation should be ensured. Sustainable and innovative practices and technologies, including agro-ecology and agro-forestry, can enhance the role of LULUCF for climate mitigation and adaptation, as well as strengthen the productivity and resilience of agriculture and forestry, according to the Regulation. Also, the LULUCF sector, including agricultural land, has a direct and significant impact on biodiversity and ecosystem services. For this reason, there must be coherence with the Union's biodiversity strategy objectives (European Union, 2018c).
The Roadmap to a Resource Efficient Europe mentions the need for EU policies to consider their direct and indirect impact on land use in the EU and globally, including indirect land use change resulting from the renewable energy policy. Land take and soil sealing should be limited to the extent possible, soil erosion reduced and soil organic matter increased. Degraded soils should be restored to a level of functionality consistent at least with current and intended use (European Commission, 2011). Guidelines were developed on best practices to limit, mitigate or compensate soil sealing (European Commission, 2012b).
The zero-pollution action plan mentioned in the European Green Deal addresses pollution of air, water and soil. Measures such as eco-schemes should reward farmers for improved environmental and climate performance, including managing and storing carbon in the soil and reduce emissions to soil and water. Also, the Green Deal mentions the promotion of production and use of new sources of protein that can relieve pressure on agricultural land, e.g. by improving the use of aquatic and marine resources (European Commission, 2019a).

2.7 EU food system global standard for sustainability

2.7.1 Farm to Fork Strategy aims for a sustainable food chain

The aim of the Farm to Fork Strategy (European Commission, 2020e) is to make the EU food system a global standard for sustainability, reduce the environmental and climate footprint of the EU food system and strengthen its resilience. A sustainable food system will be essential to achieve the climate and environmental objectives of the European Green Deal, while improving the incomes of primary producers, reinforcing EU's competitiveness and stimulate healthy diets. Also, the Strategy aims to ensure food security in the face of climate change and biodiversity loss. Efforts to tighten sustainability requirements in the EU food system should be accompanied by policies that help raise standards globally, to avoid the externalisation and export of unsustainable practices.

The following strategies should realize these ambitions:

- Move to a more plant-based diet to reduce risks of diseases and environmental impact of the food system.
- Halve per capita food waste at retail and consumer levels by 2030 (SDG Target 12.3).
- Reduce the EU's contribution to global deforestation and forest degradation.
- Reward farming practices that remove CO_2 from the atmosphere either via the Common Agricultural Policy (CAP) or other public or private initiatives.
- Reduce excess fertilisation and dependency on pesticides and antimicrobials, increase organic farming to at least 25% of the EU's agricultural land by 2030, improve animal welfare and reverse biodiversity loss.
- Reduce methane emissions from livestock by production of renewable energy and investing in anaerobic digesters for biogas.
- Place solar panels on farmhouses and barns and prioritise such investments in the future CAP Strategic Plans.
- Guarantee a decent income allowing farmers to provide for their families and withstand crises.
- Stimulate research that supports the goals, e.g. investigation of sources of alternative proteins and meat substitutes, and solutions for restoring soil health and functions.

2.7.2 CAP revision: more ambition and enforcement for environment and climate

The proposals for a new Common Agricultural Policy (CAP) for 2021 to 2027, include commitment to "aim higher" regarding the environment and climate (European Commission 2019e). At least 40% of the CAP's overall budget should contribute to climate action (European Commission 2019a). In CAP strategic Plans, Member States will set down how they intend to implement these ambitions. These plans will apply to both rural development funds (CAP Pillar II) and direct income support payments to farmers (CAP Pillar I) and will undergo a Strategic Environmental Impact Assessment. Stricter environmental conditionality for receiving CAP payments, and new eco-schemes funded under Pillar I are intended to stimulate sustainable agricultural practices. The Water Framework Directive and the Directive on the Sustainable Use of Pesticides will enter the scope of conditionality and new standards for good agricultural and environmental conditions (GAEC) will be introduced. Member States and the Commission must ensure that eco-schemes are appropriately resourced and implemented in the Strategic Plans. The Commission will support the introduction of a minimum ring-fencing budget for eco-schemes (European Commission 2019e).

3 Policy impact through a WLEFC nexus lens

Policy impact are the changes in society, economy, governance and environment, brought about by policy output. Impact always starts with changing behaviour of people. The nexus challenges and strategies to meet these challenges described in this chapter, are based on modelling results and stakeholder input from the SIM4NEXUS cases.

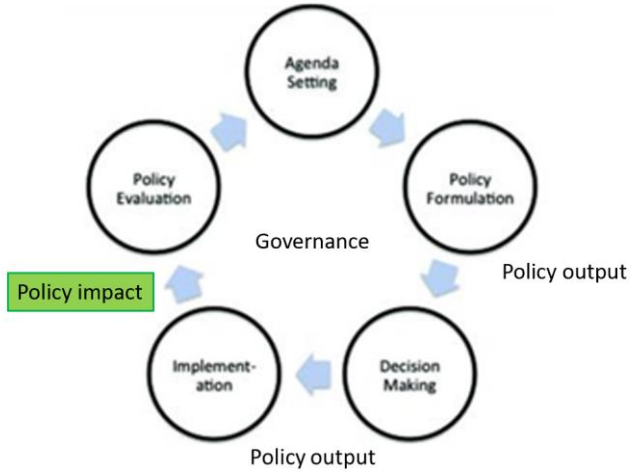

Figure 4. Position of policy impact in the policy cycle

3.1 Defining successful policy impact through a nexus lens

Criteria for judging policy impacts as successful from a nexus point of view are based on general evaluation criteria, for example used in evaluations of European policy and the Refit process (European Commission, 2020f), combined with a cross-sectoral viewpoint. The extra conditions for a nexus viewpoint are highlighted in red.

Table 1. Criteria for successful policy impact through a nexus lens (Witmer et al., 2018, adjusted)

IMPACT
Effective: Goals met in all sectors
Efficiënt and fair share of benefits and burdens for all sectors in the nexus,
Sustainable, including cross-sectoral trade-offs: People: legitimate, equal, inclusive, fair Planet: within planetary boundaries Profit: short-term affordable or self-financing, long-term profitable

3.2 Nexus challenges to fulfil European ambitions for Water, Land, Energy, Food, Climate

3.2.1 The challenge to reach all goals together

'..... a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts...'. (European Commission, 2019a).

The European Green Deal sets five strategic goals towards 2050: 1. Economic growth and prosperity, 2. Reduction of greenhouse gas emissions to zero emission in 2050, 3. Resource efficiency, 4. Conservation and enhancement of EU's natural capital, 5. Protection of citizens from environment-related risks and impacts. The biggest nexus challenge is to develop strategies and pathways that can lead to reaching all five strategic goals, as well as the uppermost sustainability goal 'Living well, within the limits of our planet' (European Commission, 2019 and 2014). Interlinkages between these goals are complex, with conflicting interests and trade-offs. Synergies must be exploited and goals and pathways that conflict must be redefined, raising the fundamental question whether all goals can be fully reached. A smart transition of the European economy and society towards low-carbon and resource efficiency, should find an efficient balance between measures that 1. Make consumption behaviour sustainable and reduce demand for energy and resources 2. Make production processes circular, energy and resource efficient and non-polluting, to reduce resource use and emissions 3. Meet the demand for energy and resources by using renewable instead of fossil raw materials, while respecting the interests of environment and people, to reduce negative environmental impacts, 4. Find feasible and affordable 'end of pipe' solutions to reduce emissions, restore damage and combat negative environmental effects, to mitigate environmental impacts, 5. Make society resilient to withstand negative environmental impacts, and 6. Stand by protection and expansion of Europe's natural capital, to combat negative environmental impacts and safeguard and increase ecosystem services. This all must be reached while economy is growing and society is prosperous and fair, according to the European Green Deal (European Commission, 2019a).
Strategies 1-4 are linked as in a waterbed. The more the demand for resources is reduced by change of consumption behaviour and increase of resource efficiency, the less resources and 'end of pipe' solutions are needed, and vice versa. However, the gap between the goals and the current situation is that big, that all strategies will be necessary.

According to SIM4NEXUS *Global* and *European* model calculations, the world would warm up approximately 3 °C above pre-industrial level by 2100 in the 'Reference scenario', that followed the Middle-of-the-road Shared Socio-economic Pathway SSP2 (O'Neill et al., 2017) and Representative Concentration Pathway RCP 6.0 (Van Vuuren et al. 2011). A combination was feasible of economic growth in Europe and a low-carbon transition that holds the increase in the global average temperature to below 2 °C above pre-industrial level with a probability of 66% (SIM4NEXUS 'Energy and Climate' scenario). However, a scenario of zero-emission in 2050 in Europe was not investigated, nor was calculated if all environmental goals of the European Green Deal could be reached while maintaining economic growth (Global and Europe SIM4NEXUS cases in Brouwer et al., 2020).
The Global and European SIM4NEXUS cases used different models to investigate a low-carbon transition between 2010 and 2050 in the 'Energy and Climate scenario'. They examined how Europe could play its part in this transition. In the 'Energy and climate scenario', Europe would reduce its greenhouse gas emissions with approximately 70% in 2050 compared to 2010, which is less ambitious than the European Green Deal.
Calculations with the models 'MAGNET' (Woltjer, Kuiper et al., 2014) and 'E3ME' (Cambridge Econometrics, 2019) showed that large scale mitigation policies in the 'Energy and Climate scenario'

would have impact on economic growth in Europe between 2010 and 2050. In the macro-econometric model E3ME, the European energy system and energy policy were modelled in detail, with detailed existing climate energy policy for Europe in the 'Reference scenario'. In the 'Energy and Climate scenario', E3ME assumed a small carbon tax and considerably increased investments in renewable energy and energy efficiency. These additional investments in the economy would result in an increase in average yearly GDP growth compared to the 'Reference scenario', from 1.42% to 1.46% over the simulation period 2010 till 2050. In the calculations with MAGNET, a computable general equilibrium model with a focus on agriculture and global trade, all mitigation measures were stimulated by a carbon tax. In this type of models, market distortions (taxes and subsidies) have the effect of reducing GDP, unless they are offsetting an existing distortion. The carbon tax in MAGNET would reduce average yearly GDP growth in Europe between 2010 and 2050 from 1.61% in the 'Reference scenario' to 1.42% in the 'Energy and Climate scenario'. However, there would still be economic growth in the 'Energy and climate scenario'.

3.2.2 Sustainable resource use trilemma

'.....the EU's energy supply needs to be secure and affordable for consumers and businesses.' (European Commission, 2019a).

The *Southwest UK* SIM4NEXUS case used the definition of energy sustainability by the World Energy Council (2019) to investigate the sustainability of their water services, drinking water supply and water purification. This definition is based on three core dimensions of energy systems: energy security, energy equity, and environmental sustainability. These interlinked objectives are considered a resource 'trilemma' due to the inherent competition and inevitable need for compromise. While it is technically possible to meet any one of the objectives in isolation, at least one but probably both other objectives would be compromised. There are numerous combinations of interventions aiming to reach the objectives, so there is no single answer. The question therefore becomes, what is the lowest-cost solution to achieve these sustainability goals, what is society willing to pay and what is the readiness of society to change behaviour and consumption? In the WLEFC nexus, this trilemma approach could be applied to water services, energy supply and the agro-food chain (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

3.2.3 Trade-offs between low-carbon and resource efficient pathways

'About half of total greenhouse gas emissions and more than 90% of biodiversity loss and water stress come from resource extraction and processing of materials, fuels and food.'
'Sustainable re- and afforestation and the restoration of degraded forests can increase absorption of CO_2 while improving the resilience of forests and promoting the circular bio-economy.' (European Commission, 2019a).

Pathways must be found that coherently combine the transitions towards a low-carbon and a resource efficient economy and society. Spotlight in European policy is currently on energy and climate, that seems to receive more political attention and priority than resource efficiency, biobased economy and the Sustainable Development Goals (Munaretto at al., 2019). This priority may lead to trade-offs from the energy transition towards other components of the WLEFC nexus, counter-acting their goals. The other way around, the transition towards resource efficiency may have trade-offs to energy goals. The transition towards renewable energy and its impact on natural resources is a central theme in the WLEFC nexus, that touches all nexus components. The SIM4NEXUS cases addressed the effects of climate policy on prices for energy and food, and trade-offs to natural resources of policies to increase bioenergy, hydropower and solar energy (Brouwer et al., 2020).

By 2018, the EU had reduced its greenhouse gas emissions with 23% compared to 1990, but the EU

is not on track towards its 2030 climate and energy targets (European Commission, 2020c; European Environmental Agency, 2019). Europe is still far away from the goal of becoming a circular economy. Resource use declined between 2010 and 2020, while resource productivity improved. Resource efficiency is expected to further improve, but with increasing material resource use (European Environmental Agency, 2019).

3.2.3.1 Trade-offs of renewable energy policy to energy and food prices

According to model calculations by the *Global* SIM4NEXUS case (Global SIM4NEXUS case in Brouwer et al., 2020), the 'Energy and Climate scenario' will lead to a growing share of renewable energy in the energy mix towards 2050, a range of +60% to +290% for the different global regions in 2050 compared to the 'Reference scenario'. In 2010, the share of renewable energy in the total energy mix was 13% and 10% globally and in Europe respectively, according to the model calculations. Emissions of greenhouse gases will be reduced -70% to -80% in 2050 compared to the 'Reference scenario'. However, higher prices for CO_2 emissions and increased competition for land in the 'Energy and Climate scenario' will lead to an increase in food prices of +3% to +30% compared to the 'Reference scenario' in 2050 in all regions of the world, as extra land is used for biomass production and land is protected to reduce emissions from land-use change. 'Food prices' mean in this case the prices of agricultural products at the start of the agro-food chain, not the prices that consumers pay at the end of the chain. If prices of agricultural products increase in a highly competitive market, there will probably be less room for environmental investments in the agricultural sector. On the other hand, in most regions of the world the area of forest will have been increased 0% to +70% compared to the 'Reference scenario' in 2050, synergetic with biodiversity ambitions, restoration of the landscape and local hydrology, climate change adaptation, and mitigating local climate change (Global SIM4NEXUS case in Brouwer et al., 2020).

The *European* SIM4NEXUS case explored various mitigation measures, including a carbon tax, to reach a low-carbon economy in Europe. It investigated the impacts of these measures on the food and energy systems. In the 'Energy and Climate scenario', bioenergy will be an important component of the transition to a low-carbon economy. The production of biomass in Europe could grow as high as 30% of agricultural production in 2050 (calculations with model MAgPIE, Europe SIM4NEXUS case in Brouwer et al., 2020). Conflicts may arise with agriculture to grow food. If bioenergy crops are produced, competition for land will result in higher land prices and therefore higher food prices. This effect is larger for energy crops than for woody biomass. However, if biomass is sourced from residues from agriculture and forestry, agriculture becomes more profitable, which might induce slightly lower food prices than in the reference scenario. Reducing emissions in the energy sector may result in higher energy prices. Also, increasing the share of renewable energy requires investments. If these costs are passed on to the consumers, this will push up prices. Increasing the use of bioenergy has a trade-off to land use and nature, as land must be allocated to produce biomass. Energy crops can be grown on degraded lands which are unsuitable for other types of agriculture (Europe SIM4NEXUS case in Brouwer et al., 2020). However, mass-production of biomass to meet a growing demand will need high yields.

Increasing the share of renewable energy in the energy mix in *Sardinia* must be speeded up to reach carbon neutrality in 2050. This will have trade-offs to energy costs that are already higher in Sardinia than in the rest of Italy (Sardinia SIM4NEXUS case in Brouwer et al., 2020).

3.2.3.2 Trade-offs in the WLEFC nexus from bioenergy

Trade-offs of bioenergy generation from wood, food and feed crops, crop residues and biogas are causing conflicts in the WLEFC nexus at all scales. There is competition between ambitious afforestation at *global* scale and food security. By 2050, globally up to 230 million more people compared to the 'Reference scenario' could be at risk of hunger under ambitious afforestation and bioenergy targets (Doelman et al., 2019). At the same time, climate neutrality of biomass is disputed and cannot be guaranteed, due to continued deforestation in tropical regions and risks of indirect land-use change, especially with fragmented international climate policy. High-carbon soils could be

converted to grow energy crops. (Global SIM4NEXUS case in Brouwer et al., 2020; Doelman et al., 2019).
An international biomass market with high sustainability standards does not exist, sustainable biomass probably will become scarce at global level and this will create competition. There is a perverse conflict of interest between high sustainability criteria and the amount of available 'sustainable' biomass. Growing bioenergy crops and deforestation may have negative impacts on the quality of water, soil and ecosystems, may counteract climate change adaptation and mitigation, competes for land and water with other uses and may cause fragmentation of ecosystems, nature areas and natural habitats. Using biomass for energy generation may be incoherent with higher value use in the biobased economy and conflicting with the cascade principle. Reducing waste in de circular economy conflicts with generating residues and waste for bioenergy. The use of biomass in numerous scattered small-scale plants will cause diffuse emissions with a negative impact on air quality (Global, European, Netherlands, Latvia, Sweden SIM4NEXUS cases in Brouwer et al., 2020).

In *The Netherlands*, biomass is an essential part of the renewable energy mix because of its potential for significant CO_2 reduction against moderate costs. The use of biomass for energy generation is likely to increase. Also, the use of biomass for a biobased economy is expected to grow. As the Netherlands is not be able to provide for its need for biomass, import will increase, shifting environmental problems, competition for scarce land and water with food production, and indirect land use change to other countries. This has led to strong polarisation between different discourses within the community of experts as well as the general public, about the sustainability of the use of woody biomass and energy crops, sustainability criteria and their accountability and enforceability. The discussion impeded investments in and extension of biomass co-fired electricity plants. Biomass is associated with co-firing in electricity plants and large- scale deforestation. In the political and public debate, there are knowledge gaps about the diversity of biomass and the best utilization of different types (Netherlands SIM4NEXUS case in Brouwer et al., 2020).
Sustainability is also a problem in biomass exporting countries *Sweden* and *Latvia*, but here, the problems are experienced within the country. In *Sweden*, there is an increasing competition between economic, environmental and recreational functions of forests (Sandström et al., 2011). The growing demand for bioenergy has led to an intensification of the forest industry (Helmisaari et al., 2014), in particular through extensions of managed forest land, introduction of fast-growing tree species and increasing use of fertilization with trade-offs to the quality of soil, water and biodiversity (Rytter et al., 2013). Changing climate conditions intensify the competition for water and impact on biodiversity. As the market for biofuels further grows, the question arises whether the supply of forest biomass for energy can further be increased. Also, harvesting biomass from forests and growing bioenergy crops including their environmental impacts should be weighed against other functions of land, water and forest, such as higher value use of wood, carbon sequestration in standing forest and natural land, biodiversity and tourism (Sweden SIM4NEXUS case in Brouwer et al., 2020).
In *Latvia*, logging and exporting wood for renewable energy production create income to the forestry sector and helps to reach renewable energy targets in the importing countries, but negative consequences for meeting the greenhouse gas emission reduction and CO_2 sequestration targets in Latvia. The growing demand for food and non-food biomass leads to an expansion of cropland and deforestation with consequences for the local microclimate, the quality of water and soil and biodiversity. Replacing wetlands by agricultural land and natural and semi-natural grasslands by arable land destroys valuable natural biotopes. Latvia: (Latvia SIM4NEXUS case in Brouwer et al., 2020).
In *Sardinia*, forests are undervalued despite their extensiveness. This is a common issue in Mediterranean countries, confirmed by stakeholders. Wood biomass could play an important role in the Mediterranean region if harvested and used in a sustainable way. However, the wood biomass value chain is nearly inexistent, all wood pellets are imported. Also, wood is used for heating mostly using low-efficient fireplaces (Sardinia SIM4NEXUS case in Brouwer et al., 2020). From the opposite view, the property of forests to buffer heat and capture and store water in the soil will be of

increasing value in the Mediterranean with a changing climate, and forests may be affected by climate change.

In the *Upper Rhine* region, the government stimulates with support mechanisms the generation of bioenergy, especially biofuel and energy from methanation. This creates land use change, and competition with food production, and puts pressure on water quantity and quality. The existing legislative framework aims at minimizing these negative impacts, however the safeguards defined by this legislative framework seem insufficient (Strosser et al., 2018, p95) and do not consider the possible negative impacts on water (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020).

The *Southwest UK* SIM4NEXUS case reported that subsidised digesters to produce biogas on farms, stimulated by financial incentives from the government, increased the demand for maize, competing with food and feed production and leading to increased use of fertilizers and pesticides. Land is being left bare and subject to soil erosion. Also, long-term contracts may conflict with agro-environmental schemes, and land becomes over-priced. Subsidies were granted without questioning the efficiency of this way of energy generation or energy use. The Latvian case also reported growing demand for land to produce energy crops for digesters (Latvia and Southwest UK SIM4NEXUS cases in Brouwer et al., 2020). The *Eastern Germany-Czech Republic-Slovakia* SIM4NEXUS case reported the inefficiency of energy generation from biogas, and the competition for land caused by large-scale monoculture of energy crops, and environmental impacts. Also, biogas stations inevitably lose methane, one of the most potent greenhouse gases. Finally, the case doubts that this way of energy generation is driven by demand or subsidies (Eastern Germany-Czech Republic-Slovakia SIM4NEXUS case in Brouwer et al., 2020).

3.2.3.3 Land take by solar and wind farms

In the *Upper Rhine* region and *Latvia*, solar farms are expected to further develop. Solar and wind farms compete for land (or sea) and affect landscapes, vegetation and soil (Latvia and Upper Rhine SIM4NEXUS cases in Brouwer et al., 2020). The same problems manifest in many Member States.

3.2.3.4 Energy generation affects and depends on water

According to model calculations, water withdrawal for electricity generation is expected to substantially decrease in *Europe* due to reduced need for cooling water as the number of traditional coal-fired power plants will decrease. In the 'Energy and Climate' scenario, this process is faster, leading to lower water withdrawal by 2050. In contrast, water use for hydropower is expected to increase (Europe SIM4NEXUS case in Brouwer et al., 2020).

Hydropower affects water quantity, quality, fish migration, land use and biodiversity, and there is uncertainty about continues water availability because of climate change. *Swedish* law prohibits hydropower constructions in four of the biggest streams and several smaller rivers, and thus limits further expansion of hydropower. Hydroelectricity plays a key role in energy supply in the *Upper Rhine* region, *Latvia* and *Sardinia* (Latvia, Sardinia, Sweden, Upper Rhine SIM4NEXUS cases in Brouwer et al., 2020).

Dependence on water supply for energy production will be at least maintained in the *Upper Rhine* region. The energy model 'E3ME' calculated that it is impossible to pursue both objectives, decarbonization of the energy mix and a nuclear phase-out. Reliance of water for cooling is risky in a climate change context with increasing frequency and severity of droughts (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020).

3.2.3.5 Trade-off from resource efficiency to energy use

The other way around, efficient use of resources may cost energy. For example, as part of modernizing the irrigation system, the Spanish water delivery system was changed from surface irrigation to pressurized systems. This required the installation of electric pumps to guarantee sprinklers or drip irrigation to function properly, which considerably increased the energy use of irrigated agriculture in *Andalusia* (Andalusia SIM4NEXUS case in Brouwer et al., 2020).

3.2.4 Agriculture and food: large environmental impact and vulnerable to climate change

'Although the transition to more sustainable systems has started, feeding a fast-growing world population remains a challenge with current production patterns. Food production still results in air, water and soil pollution, contributes to the loss of biodiversity and climate change, and consumes excessive amounts of natural resources, while an important part of food is wasted. At the same time, low quality diets contribute to obesity and diseases such as cancer.'
'..... stimulate sustainable food consumption and promote affordable healthy food for all.'
'.....improved nutrient management to improve water quality and reduce emissions.'
(European Commission, 2019a).

The agriculture and food sectors play a key role in the sustainable use of natural resources and human health. In the WLEFC nexus, the challenges are how to keep healthy food available and affordable to end hunger and undernourishment, prevent diet-related diseases, stimulate efficient use of energy, water and land in the agro-food chain, reduce emissions, environmental damage and footprints in and outside Europe, and stimulate the delivery of environmental services by the agricultural sector. Other challenges are a decent income for farmers, improvement of the economic position of farmers in the agro-food chain and creation of business models for sustainable farming. In the meanwhile, agriculture is vulnerable and must adapt to droughts, flooding and temperature rises related to climate change.

3.2.4.1 Trade-offs in the WLEFC nexus created by food consumption

Current food consumption patterns are unsustainable from both health and environmental points of view. Agriculture is responsible for 10% of the EU's greenhouse gas emissions. This share is 25% if emissions from agriculture, forestry and other land use (AFOLU) were included. Of the agricultural emissions without AFOLU, livestock accounted for 70% in 2010. According to model calculations of the 'Reference scenario', this share may increase to 75% in 2050 while absolute emissions will decrease, because emissions from other sectors will decrease further (Europe SIM4NEXUS cases in Brouwer et al., 2020). Of the total agricultural land, 68% is used for animal production (European Commission, 2020e). *Europe* had in 2010 a food supply of more than 3000 kcal per capita per day, which indicates sufficient food availability. The food supply in calories consisted of one quarter of animal-based and three quarters of plant-based products. An estimated 20% of the total food produced is lost or wasted in Europe, of which 70% by households, food services and retail (Stenmarck et al., 2016).

3.2.4.2 Trade-offs between economic, ecological and societal targets of agriculture

Conflicts exist between agricultural production and food security on the one hand, and the need to reduce emissions and resource use on the other hand. According to the *Southwest UK* SIM4NEXUS case, all measures that increase the area of agricultural use or yields per hectare, have negative impacts on land, water and biodiversity. Most measures that reduce environmental impacts decrease yield per hectare or area available for agricultural use, and those which do not are of limited benefit (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

Putting the burden of environmental measures, such as a greenhouse gas emission tax or water pricing, on the shoulders of *Europe*an farmers will increase prices of European agricultural products and affect farmer's positions on the highly competitive global market. A good income and financial position of farmers are necessary to invest in environmental innovations, such as precision farming and the development of non-irrigated and less water demanding crops. Agricultural commodity prices rise under the 'Energy and Climate scenario' for various reasons. Firstly, greenhouse gas emissions in the agro-food chain are taxed, and the tax burden of the remaining emissions is rolled over to consumers. Prices for animal agricultural products will rise higher than for crops, as livestock farming emits 70% of total agricultural greenhouse gases. Secondly, expanding areas with forests will lead to growing land scarcity and therefore higher land rents, which are also rolled over to consumers.

Thirdly, if no tax were levied on greenhouse gases, but other regulations would be enforced to implement mitigation measures, this too would increase production costs. The combined effect explains the substantial rise in prices for agricultural commodities and food, which may cause a trade-off to food security for consumers. Compensating measures could mitigate this effect, such as redistribution of tax income to consumers, financial support to invest in innovations and increasing yields, or shifts in diets from animal to plant-based food (Doelman et al. 2019). This trade-off between mitigation and food security is consistent with the findings of Hasegawa et al (2018), van Meijl et al (2018) and Frank et al (2019) (European SIM4NEXUS case in Brouwer et al., 2020).
About 64% of the agricultural production in *Andalusia* is from irrigated agriculture. It generates 63% of agricultural employment and 67% of farm income, so it has high socioeconomic importance (Massot, 2016). However, it also puts pressure on the limited water resources. Because of a change from surface irrigation to pressurized systems, energy demand for irrigation has increased. The Ministry of Industry subsidized energy for irrigation with a special rate until July 2008, after which the energy market was liberated and brought about higher energy prices for irrigators (Andalusia SIM4NEXUS case in Brouwer et al., 2020).

3.2.4.3 Agriculture impacts and dependence on the landscape

Intensive large-scale agriculture is the driver behind landscape degradation and disturbance of hydrological cycles and local climate in the *Czech Republic and Slovakia*. Drainage of agricultural land and cultivation of wetlands have direct impact on the ability of the landscape to retain water. This will fundamentally change the hydrological cycle and local climate, deteriorate the quality of the soil, and increase the risk of drought and flooding. Landscape degradation has happened despite the EU's efforts to introduce agro-environmental schemes and measures to mitigate climate change. Degradation of the agricultural landscape will backfire agricultural yields and production (Eastern Germany-Czech Republic-Slovakia SIM4NEXUS case in Brouwer et al., 2020).

3.2.4.4 Agriculture impacts and dependence on water quantity

Water scarcity during the growing season is an increasing problem for agriculture in the Mediterranean (Greece, Sardinia, Andalusia SIM4NEXUS cases in Brouwer et al., 2020). A sharp increase in agricultural productivity over the last 50 years in Sardinia has been associated with both intensification and mechanization of agriculture, with a strong increase in irrigation. Currently, agriculture reaches a share of about 70% of total blue water consumption in *Sardinia*. As an effect of climate change, the occurrence and intensity of periodical droughts is increasing. The relatively small farms, high energy costs, and relatively low production are determining a general land abandonment and contraction of the market. Increasing food production and improving value chains to allow export is an important challenge for the region, with relevance for all nexus components (Sardinia SIM4NEXUS case in Brouwer et al., 2020).
In the *Upper Rhine* region, irrigated area and water demand for irrigation are expected to increase in Baden-Württemberg, despite an overall decrease in water use per hectare (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020).
Climate change will increase the risk of crop failure. The vulnerability of the agricultural sector to climate change could have an impact on social stability and political independence of *Azerbaijan*, as 40% of the working population is employed in the agricultural sector. A potential dependence on food imports in case of reduced productivity because of climate change is seen as are severe risks for the country by stakeholders (Azerbaijan SIM4NEXUS case in Brouwer et al., 2020).
At *global* scale, the 'Energy and Climate' scenario will lead to a slight increase of irrigation water demand due to an increasing demand for bioenergy, and due to the need to intensify the crop production to spare land from deforestation (Global SIM4NEXUS case in Brouwer et al., 2020).

3.2.4.5 Agriculture impacts on water quality

Run-off and leaching from agricultural land is the main source of nitrogen in surface water and groundwater (European Environmental Agency, 2019). While the deterioration of water quality has been stabilized or turned into some improvement especially in Western *Europe*, in Eastern Europe

eutrophication is expected to increase due to agricultural intensification (Europe SIM4NEXUS case in Brouwer et al., 2020).
Eutrophication of surface water caused by point and diffuse pollution such as agricultural land and production forestry, is a prevailing problem in *Latvia*. More frequent rain events will increase the load of suspended matter and nutrients to lakes and rivers. Nutrient concentrations in lakes will rise and the risk of low-oxygen periods will increase. Agro chemicals such as pesticides, antibiotics and hormones will also negatively impact water quality. In Sweden, increasing temperatures, shifts in seasonality and more rainwater runoff will cause higher nutrient loads (Latvia and Sweden SIM4NEXUS cases in Brouwer et al., 2020).

3.2.4.6 Dilemma of organic farming

Model predictions for *Latvia* indicate an increase in the production of cereals along with expansion of cereals export. To balance economic and environmental considerations, policy measures are needed to ensure good land use practice and avoid large-scale monoculture, keep a balance between agricultural and natural land, and stimulate precision use of fertilizers while growing highly productive cultivars. Organic farming takes better care of the environment than intensive regular farming but needs more land as yields per hectare are less (Latvian SIM4NEXUS case in Brouwer et al., 2020).

3.2.5 The undervalued vital roles of the landscape, ecosystem services and water

'Ecosystems provide essential services such as food, fresh water and clean air, and shelter.'
'.... it is essential to increase the value given to protecting and restoring natural ecosystems...'
'The natural functions of ground and surface water must be restored.'
'.....lasting solutions to climate change require greater attention to nature-based solutions...'
(European Commission, 2019a).

3.2.5.1 Ecosystem services are vital but degrading

Increasing demand for biomass, food and feed require a growing agricultural production and intensifies competition for land and water. Land take and soil sealing continue predominantly at the expense of agricultural land, soil degradation is not well monitored but probably widespread (European Environmental Agency, 2019). The landscape has been drained and has dried out, leading to disturbance of hydrological cycles, drought, floods and overheating. Soils have degraded, lost carbon and capacity to absorb water. Urbanisation leading to soil sealing and run-off, and intensification of agriculture leading to large drained plots with monoculture, are driving forces behind these negative developments (Eastern Germany-Czech Republic-Slovakia case in Brouwer et al., 2020).
The growing demand for food and non-food biomass can lead to an expansion of croplands and deforestation with consequences for the microclimate. According to the Guadalquivir River Basin Authority, 25% of the precipitation in the basin comes from evaporation in internal water bodies (Latvia and Andalusia cases in Brouwer et al., 2020).
Only 40% of surface water bodies is in good ecological status and wetlands are widely degraded, as are 80-90% of floodplains. Water abstraction and diffuse pollution will continue, particularly driven by agriculture and energy production, and water systems will continue to suffer from hydromorphological change (European Environmental Agency, 2019).
Temperature and precipitation are projected to increase more in high-latitude regions such as *Sweden* than in the rest of Europe (IPCC, 2014; Jacob et al., 2014). Since high-latitude ecosystems have adapted to low natural energy flows, they are relatively more sensitive to a shift in climate, physical and biogeochemical conditions (Roots, 1989) (Sweden case in Brouwer et al., 2020).

3.2.5.2 Disturbance of balance between water demand and supply intensified by climate change

Climate change will increase the frequency and intensity of droughts, enlarging the gap between water demand and supply. Agriculture is the dominant sector in water demand, particularly irrigated

agriculture. In addition, the electricity and industry sectors and households have a substantial water demand. Especially in arid regions, like the *Mediterranean*, and in whole *Europe* during dry periods of the year, scarcity can lead to competition between different sectors and negative environmental impacts. *Andalusia,* for example, has a negative water balance and faces problems of erosion in some areas, with a risk of desertification (Andalusia SIM4NEXUS case in Brouwer et al., 2020). The balance between water demand and availability has reached critical and unsustainable levels of exploitation in *Sardinia* with environmental consequences for keeping Minimum Environmental Flows. After repeating periods of consecutive years with low precipitation, the reservoir system has not recovered enough to satisfy all demands, leading to water shortages for crops, domestic use and generation of hydropower. Saline intrusion is affecting coastal aquifers. Reduced water flows deteriorate water quality because less water is available to dilute pollutants. Besides water shortage, an additional challenge is the higher inter and intra annual variability of precipitation and heat, which is projected to increase with climate change (Sardinia SIM4NEXUS case in Brouwer et al., 2020).
In *Sweden*, water availability is likely to decline because of increasing evaporation rates in large parts of the country, especially during summer (Eklund et al., 2015). Water shortages during summer will increasingly affect the drinking water supply, both in terms of quality and quantity. Climate change will increase the risk of water scarcity and the growing need for bioenergy will intensify the competition for land and water (Sweden SIM4NEXUS case in Brouwer et al., 2020).
Runoff will decrease in *Latvia*. An increase in extreme events has already been observed, particularly more and longer periods of drought (Latvia SIM4NEXUS case in Brouwer et al., 2020).

3.3 WLEFC nexus strategies for effective and efficient policy impact

'..smart integration of renewables, energy efficiency and other sustainable solutions across sectors will help to achieve decarbonisation at the lowest possible cost'. (European Commission, 2019a).

3.3.1 Maximum impact against lowest cost: 'Upstream thinking'

The Global, European and Southwest UK SIM4NEXUS cases experimented in their modelling with lowest cost strategies for supply chains of water, energy and food, that would have most synergies between the objectives of resource security, environment protection and human equity in the WLEFC nexus. They found a strategy to meet these criteria, namely prioritising policies in the following order: 1. Change consumption behaviour to decrease demand for products, 2. Increase efficiency to reduce resource use and emissions 3. Meet remaining and potentially growing demand with renewable natural resources, investing in more sustainable production methods to reduce environmental impact of supply. SIM4NEXUS called this strategy 'Upstream thinking', after a policy in the *Southwest UK* SIM4NEXUS case for the drinking water supply chain. According to this policy, it is cost-effective and more environmentally responsible to help farmers deliver cleaner raw water than it is to pay for expensive filtration equipment. Therefore, 'Upstream Thinking partnership' was initiated with the aim to improve raw water quality and water storage in the natural landscape to make the provision of drinking water more sustainable. This is an example of literal 'Upstream thinking'. The term can also be used figuratively to indicate that the most cost-effective and synergistic strategy is to take measures as early as possible in the order of decreasing consumption, increasing efficiency, and using renewable resources in a sustainable production process. The *Southwest UK* SIM4NEXUS case confirmed this lowest-cost order of policies in its 'trilemma' approach, based on System Dynamics Modelling (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

Lowest cost may be true from the viewpoint of commodities and supply chains, but many businesses and jobs depend on unsustainable consumption and production. A fundamental change in consumption behaviour implies a system shift of society and economy. There will be losers in this transition, who must be supported to change their business. There will also be new opportunities that

can be seized. For example, livestock farmers need to change their business, but prices of land will reduce as more land will become available, and horticulture and arable farming will increase (European and Global SIM4NEXUS cases in Brouwer et al., 2020).
In the Roadmap to a Resource Efficient Europe, it is mentioned that resource efficiency can reduce costs, but often requires initial investments (European Commission, 2011). Also, a lowest-cost transition may go against the wish of consumers. There is a willingness to pay for more expensive solutions by those who can afford it, as long as they do not have to change their lifestyles and behaviour. There is resistance against changing behaviour anyway. The Roadmap to a Resource Efficient Europe already in 2011 advised to ensure better understanding of consumer behaviour (European Commission, 2011).

3.3.1.1 Upstream thinking in the energy chain

The *European* case modelled several variants of the 'Energy and Climate scenario' using different strategies, to investigate their separate impacts on the energy transition:

1. Energy savings by changing behaviour and increase energy efficiency, which reduces the overall demand for energy and need to burn fossil fuels.
2. A structural change in energy production and use, a transition from coal and gas to renewable sources of electricity and using biofuels for transport.
3. Negative emissions from the use of bioelectricity with carbon capture and storage (BECCS).

The conclusions were that the main synergies and lowest cost solutions are all associated with reduced energy demand by changing consumption behaviour and increasing resource efficiency, if lower energy prices do not evoke rebound effects, such as higher energy use because of lower energy bills. Therefore, it is important that energy efficiency gains are not simply a technical feat but are paired with societal awareness on the importance of reducing emissions from energy consumption. To achieve impact, social acceptance is needed.
BECCS would require a significant amount of biomass, which in turn uses water, land and other agricultural resources, according to the modelling (Europe SIM4NEXUS case in Brouwer et al., 2020).
The cost-effectivity of reducing energy demand for the energy transition was confirmed by the *Upper Rhine* and *Sardinia* cases. Reduction of energy use is synergistic with goals for water, land, food security, biodiversity and climate. Sardinia aims at reaching carbon neutrality by 2050. Development of alternative energy sources (mostly wind), is increasing at a fast rate. Increase in hydropower has impact on the water system and may become less certain because of climate change. To reach the goal, other fundamental actions must be taken, among these the improvement of energy efficiency in buildings (Upper Rhine and Sardinia SIM4NEXUS cases in Brouwer et al., 2020).

3.3.1.2 Upstream thinking in the food chain

The main synergy within the WLEFC nexus exists between objectives for improving human health related to food intake and diet, and objectives for reducing greenhouse gas emissions and environmental impacts by the agro-food chain. According to model calculations by the *Global* SIM4NEXUS case (IMAGE, Global SIM4NEXUS case in Brouwer et al., 2020), a shift to reduced consumption of animal products, in line with sustainable diets as proposed by Willett et al. (2019), combined with a reduction of waste in the agro-food chain, will result in a sharp reduction of prices for agricultural food products. This is related to reduced land use for livestock production and reduced consumption of feed crops by animals, making more agricultural land available for food crops for human consumption. The reduced demand for feed crops allows to cultivate crops only in the most productive areas and requires less investments into land-sparing technological change. The reduction in overall agricultural production leads to a decline of land and water used for agriculture, resulting in an increase of available water and forested area (Forested area + 2% to +30% in 2050 compared to 'Reference scenario'), reduced greenhouse gas emissions (-2% to -14% in 2050 compared to 'Reference scenario') and reduced nitrogen concentration in surface water (-1% to -16% in 2050 compared to 'Reference scenario') which are also important synergies. As there are no major trade-offs in this analysis, it seems that replacing animal by plant-based food in the human diet is a policy

with a lot of synergy in the WLEFC nexus. However, the transition from animal to plant-based diets will force livestock farmers to change their business. On the other hand, it will bring opportunities in horticulture and arable farming, and will increase the availability and reduce prices of farmland as less land is needed for feed crops (Global SIM4NEXUS case in Brouwer et al., 2020).
European model calculations used the diet scenario according to Frank et al. (2019), assuming a replacement of 35% of animal by plant-based food consumption in 2050, and a gradual transition over the period 2020-2050 in Europe. This scenario leads to similar conclusions as drawn by the global case. A diet shift in the 'Energy and Climate scenario' would also reduce the prices of crops and livestock products compared to the 'Energy and Climate scenario' without the diet shift. However, in this scenario, livestock farmers would be hit by both a reduction in demand for their products because of the diet shift, and an increase in costs because of the mitigation measures to reach the 2 °C climate goal (European SIM4NEXUS case in Brouwer et al., 2020).

3.3.1.3 Upstream thinking in the water chain

In *Sardinia*, sustainable water management cannot be reached without improving irrigation efficiency in agriculture and reduction of water losses in the hydraulic conveyance system. Technological improvements could not only reduce water demand per irrigated hectare to an estimated 30 to 50%, but also reduce fertilization requirements, with economic benefits for the farmer and less emission of nutrients to the environment. Efficient water use and reduction of water losses will increase the amount and stability of food production and serve biodiversity. More water will be available for hydropower and less energy is needed for water pumping (Sardinia SIM4NEXUS case in Brouwer et al., 2020).

3.3.2 Implement synergistic environmentally targeted measures

Another strategy is to combine as many measures as possible and feasible that are mutually synergistic and have more positive effects when implemented together than separately.

The *Global* case modelled a 'WLEFC nexus target scenario' that combined environmentally targeted scenarios for energy and climate ('Energy and Climate scenario', carbon pricing is main driver), biodiversity and land (protecting nature areas and biodiversity), water (reducing water demand and pollution) and agriculture and food (change diet, reduce waste, increase resource efficiency). This 'WLEFC nexus target scenario' lead to further improvement of WLEFC targets than the separate target scenarios for each WLEFC nexus component, highlighting the synergies. Greenhouse gas emissions are even further reduced in the 'WLEFC nexus target scenario' (-71% to -85% in 2050 compared to 'Reference scenario') than in the 'Energy and Climate scenario' (-66% to -88% in 2050 compared to 'Reference scenario') because additional natural land is protected and agricultural production is reduced due to less consumption of animal-based food. Also, water withdrawal is further reduced (-10% to -30% in 2050 compared to the 'Reference scenario'), because water use is reduced in fossil-fuel based energy production due to climate policy, in irrigation due to lower consumption of animal-based food, as well as due to further efficiency improvements. The food prices, however, are slightly less low in the 'WLEFC nexus target scenario' (-34% to -58% in 2050 compared to the 'Reference scenario') compared to the target scenario for agriculture and food (-43 to -59% in 2050 compared to 'Reference scenario') as the reduced pressure in the food system due to lower consumption of animal-based food, is counteracted by a slight increase in pressure due to stricter land protection from both biodiversity and climate mitigation policies. Lower demand for animal-based food results in less crop as well as livestock production, and therefore reduces fertilization requirements and nutrient emissions. A decrease of agricultural land offers opportunities for less intensive farming, for example organic, for growth of biomass and enlarge nature areas, and allows for a more efficient allocation of the remaining food production on land that is most suitable with less environmental impacts. An increase in nature areas and forest have positive impacts on climate change mitigation and adaptation, as well as the hydrological cycle. More absorption of greenhouse gases by forests provides the energy sector with more flexibility in the selection of resources and technologies it can use to

supply the energy demand. Therefore, in the 'WLEFC nexus target scenario', the renewable energy share increases only by 38% in 2050 compared to the reference scenario, approximately 10% lower than in the 'Energy and Climate scenario' and achieving the same reduction in greenhouse gas emissions. Also, they found that improving nitrogen efficiency in agriculture reduces emissions and is synergistic with climate change mitigation, improving the quality of groundwater and surface water and protection and restoration of biodiversity (Global, Europe, Latvia SIM4NEXUS cases in Brouwer et al., 2020).

3.3.3 The nexus value of protecting and restoring the landscape and ecosystems

The case *Eastern Germany-Czech Republic-Slovakia* has been focusing on the impact of large drained agricultural fields and large sealed urban areas on the water regime and on the air temperature, looking at the distribution of solar energy. This resulted in a passionate plea for paying attention to the role of land cover and land use changes in the local and regional hydrological cycle, climate change and carbon sequestrationWater retention and support of permanent vegetation may cool down the land relatively soon, with higher primary production and carbon accumulation in the recovering soil. Rainwater is the driving force of ecosystem recovery, atmospheric CO_2 reduction and thermoregulation of the landscape. This rainwater is currently flowing into rivers and oceans, causing peak flows without benefit for the land. Measures to retain rainwater in the landscape are based on the principle of slowing down the flow of rainwater from higher to lower places, to give it the opportunity to infiltrate and replenish the groundwater. In this way it can form a water buffer that feeds the base flow of rivers and streams during dry seasons. Measures include restoring natural courses of streams, wetlands, patches of forest and rows of trees, and constructing terraces, ponds, small dams in streams, gullies and balks perpendicular to the slopes. By retaining rainwater in damaged ecosystems, the renewal of vegetation begins, carbon sequestration, soil and groundwater reserves improve, springs are renewed, water vapour is increased and solar energy is transformed into latent heat that is transferred to higher, cooler layers of the atmosphere. There, at the dew point, this latent energy is transformed into sensible heat. The generated rainfall returns to the ground and feeds the ecosystems, stimulates vegetation growth, carbon sequestration and thermoregulation in the landscape. Clouds reduce the entering of solar radiation. This functional model can be quantified and implemented at individual, local, regional and global levels. A Landscape Recovery Programme is running in the Košice Region in Eastern Slovakia on restoring ecosystem services, natural resources and carbon sequestration via primary production and retention in the soil. The return on invested money is expected to be less than 3 years (Eastern Germany-Czech Republic-Slovakia SIM4NEXUS cases in Brouwer et al., 2020).

The important role of land cover and agricultural practices for the hydrological cycle, water quantity and quality, biodiversity, soil quality and climate change mitigation and adaptation are confirmed by the Latvia, Andalusia, Upper Rhine, Sardinia, Southwest UK and Sweden SIM4NEXUS cases (Latvia, Andalusia, Upper Rhine, Sardinia, Southwest UK and Sweden SIM4NEXUS cases in Brouwer et al., 2020).

In *Latvia,* there is a growing demand for food and non-food biomass, which can lead to an expansion of cropland and deforestation with consequences for the microclimate. Expansion of cropland should integrate landscape-saving measures and not lead to landscape-degrading monoculture (Latvia SIM4NEXUS case in Brouwer et al., 2020).

The importance of keeping the hydrological cycle and essential elements in this cycle in good condition is demonstrated in *Andalusia*. Water bodies may affect climate at local level. According to Guadalquivir River Basin Authority, 25% of precipitation in the basin comes from evaporation in internal water bodies. (Andalusia SIM4NEXUS case in Brouwer et al., 2020).

In *Sardinia*, the value of forests should be assessed and widely recognised (Sardinia SIM4NEXUS case in Brouwer et al., 2020).

3.3.4 The nexus value of nature-based solutions.

According to Munaretto et al (2017), nature-based solutions to prevent drought and floods and support climate change mitigation and adaptation are more synergistic with other European objectives in the WLEFC nexus than purely technical solutions. For example, wetlands and floodplains can be restored and afforestation increased to adapt to climate change, rather than build a water reservoir or increase groundwater pumping. *Globally*, biodiversity protection and restoration can have synergies with climate change mitigation as 'natural climate solutions', but may also put risks to food security, similar to the use of bioenergy (Global SIM4NEXUS case in Brouwer et al., 2020). Nature-based climate solutions can help address climate change in three ways:

- Reducing greenhouse gas emissions related to land use and changes in land use
- Capturing and storing additional carbon dioxide from the atmosphere
- Improving resilience of ecosystems, thereby helping communities adapt to the increase in flooding and dry spells associated with climate change (Nature Conservancy, assessed 1 August 2020).

In *Sweden*, drained peatlands are wettened again, which leads to decreasing greenhouse gas emissions. The extended growing season that arises from warmer temperatures in the future, particularly in the North, means that some areas will become increasingly available and attractive to forestry. This warming might also imply a shift in vegetation types and a shortening of the presently rather long rotation periods of boreal forests. Consequently, one of the key questions is whether the extraction of forest biomass can be further increased in the future without negative consequences for other forest functions and for water availability and quality (Sweden SIM4NEXUS case in Brouwer et al., 2020).

4 Policy output through a WLEFC nexus lens

Policy output is the direct result of a policy-making process, for example a plan with goals and objectives, implementation programmes and instruments such as laws, levies, education programmes.

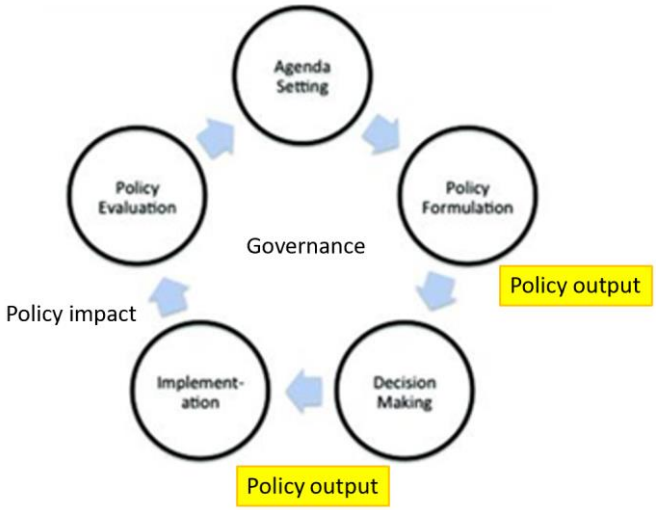

Figure 5. Position of policy output in the policy cycle

4.1 Defining successful policy output

Successful nexus policy output is defined, based on criteria for policy evaluation by the EU (European commission, 2020f), supplemented with a nexus view. Relevance looks at the relationship between the needs and problems in society and the objectives of the intervention, as well as how the policy corresponds to wider EU policy goals and priorities. Nexus policy coherence refers to the quality of policies to maximally exploit synergy between objectives, measures and instruments, and assess trade-offs and conflicts within and between policies, to avoid, mitigate or compensate trade-offs, in this order of priority. Relevance and coherence have some overlap in the requirement that policy corresponds to wider policy goals and priorities.

Table 2. Criteria for successful policy output through a nexus lens (Witmer et al., 2018, adjusted)

OUTPUT
Relevant objectives, programmes and instruments, also cross-sectoral * Objectives address needs and problems of society * Policy supports wider EU policy goals and priorities
Horizontally coherent objectives, programmes and instruments, also cross-sectoral: * Synergies exploited * Trade-offs recognized and 1. avoided, 2. mitigated or 3. compensated with transparent policy choices, if objectives cancel each other

Vertically coherent objectives, programmes and instruments, also cross-sectoral:
* Higher level supports lower level objectives and instruments
* Lower level implements higher level objectives and instruments, coherent

4.2 Incoherence, gaps, ambiguities, implementation barriers in WLEFC policies

'All EU actions and policies will have to contribute to the European Green Deal objectives. The challenges are complex and interlinked.'
*..... all of these areas for action are strongly interlinked and mutually reinforcing, careful attention will have to be paid when there are potential trade-offs between economic, environmental and social objectives (*European Commission, 2019a).
'Goals can be reached in multiple ways and all pathways entail some trade-offs between sectors, there isn't one single optimal strategy.' (Sardinia case in Brouwer et al., 2020).

4.2.1 (In)coherence between European WLEFC policies

4.2.1.1 Horizontal (in)coherence

Coherence and incoherence between EU policies relevant for the WLEFC nexus were assessed by Munaretto et al., 2017). They scored the bilateral coherence between 33 selected EU objectives for water, land, energy, food and climate (WLEFC), laid down in policy documents. They used a system developed by Nillson et al (2012) and based the scoring on literature and expert judgement. The attainability to reach one objective was estimated, when progress would be made in reaching another objective, and vice versa. The ten national and regional cases did the same for selections of national and regional policies (Munaretto et al., 2019). They found that the coherence scores depended on assumed context, measures, and pathways to implement the policy to reach the objectives. In other words, coherence and incoherence between policy objectives very much depend on how policies are implemented. Most intrinsic conflicts between policy objectives were observed when there was competition between scarce resources such as land and water. Several cases confirmed the results of these qualitative analyses by modelling the impacts of policy interventions on the WLEFC goals (Europe, Sweden, Greece, Netherlands, Southwest UK SIM4NEXUS cases in Brouwer et al., 2020).

Munaretto et al., (2017 and 2019) concluded that more European policy objectives, as laid down in policy documents, are mutually synergistic than conflicting. However, conflicts between policies that seem synergistic 'on paper' may cause conflicts when implemented. Also, they found that interlinkages between policies in the WLEFC nexus concentrate around 'nexus critical nodes'. Most trade-offs were caused by economic objectives and synergy by environmental objectives. Trade-offs are caused by the Renewable Energy Directive (RED) and the Common Agricultural Policy (CAP). Policy objectives with the highest risk for trade-offs in the WLEFC nexus are 'Increase the use of renawable energy' if this energy is generated by food and feed crops, woody biomass and hydropower, 'Increase the competitiveness of agriculture' if this implies intensification of agriculture, and 'Support the development and uptake of CCS technology'. Policymakers should be aware that progress in achieving these objectives may come at the expense of other objectives in the WLEFC nexus.
The objective 'Ensure sufficient supply of good quality water for people's needs, the economy and environment' is most vulnerable for trade-offs, as it is most influenced by other policy objectives in the WLEFC nexus. At the same time, most synergy is created by this same water objective, as well as by the land objectives 'Restore degraded soils to a level of functionality consistent with at least current and intended use' and 'Prevent soil degradation'. These objectives reinforce each other, serve production of energy, facilitate climate change adaptation, reduce greenhouse gas emissions, may

help increase farm incomes and support rural areas economy. Furthermore, in the agricultural sector, only if the greening and cross-compliance conditions are fulfilled, the objective 'Contribute to farm incomes' supports the achievement of water, land and climate objectives. Finally, the objective 'Promote resource efficiency in the agriculture, food and forestry sectors' supports water and energy efficiency and availability of land and water, may prevent land degradation and indirect land use change, and supports the development and uptake of low-carbon technology. (Munaretto et al., 2017 and 2019).

Mainstreaming environmental objectives in fundamentally economic policy does not solve the conflicts and trade-offs between these interests. There are internal conflicts in the CAP between economic and ecologic interests and objectives, which cause implementation problems between water, land, energy, food and climate (WLEFC). Also, there are conflicts of interest in the Renewable Energy Directive between increasing the generation of renewable energy and the appliance and strictness of sustainability criteria. Lack of priority to sustainability issues often puts emphasize on the short-term economy rather than long-term sustainability.

Linkages and potential trade-offs between policies are mentioned and addressed in European policy documents, for example the cross-compliance in the CAP, and the environmental and societal trade-offs from bioenergy in the RED, but not all. Options for synergy are rarely mentioned in policy documents (Munaretto et al., 207). Also, not all potential trade-offs from policies are addressed in policy documents, for example:

- No connection is made between the RED and the CAP, even though the RED pushes the growth of bioenergy crops.
- Sustainability criteria in the RED for biobased renewable energy produced in Europe as well as abroad, are experienced as unclear and insufficient (Netherlands, Latvia, Sweden cases in Brouwer et al., 2020).
- Negative impacts of biodigesters on farms are not addressed in the RED and CAP.
- The dependency and vulnerability of renewable energy generation on the availability of water in the context of climate change are not addressed in the RED.
- The effects of increasing bioenergy on food security and affordable food prices are weakly addressed in the RED. The EC will monitor the effects on food prices, but no concrete actions on unwanted effects are described.
- Impacts on land caused by the stimulation of renewable energy are better addressed and more strictly regulated in EU policies than impacts on water. The objective 'Fully consider water and ecosystem footprints of alternative climate change mitigation measures' (UNEP, 2012) is not referred to in the RED, for example negative effects of hydropower on aquatic ecosystems, water quality and water quantity are not addressed. In general, impacts on water availability and quality, and on aquatic ecosystems are left to voluntary schemes and not regulated in the RED.
- Trade-offs of large-scale monoculture agriculture to the landscape and local hydrological cycle are not addressed by the RED and the CAP. Cross-compliance with the Water Framework Directive in the CAP, as suggested in the current proposals for the CAP revision, would help to protect and improve water quality, but not water quantity, the landscape and local hydrological cycles.

4.2.1.2 Vertical (in)coherence

According to the ten national, regional and transboundary SIM4NEXUS cases, European policies for WLEFC have been integrated into national and regional policies. The main factors that hinder implementation of these policies are: horizontal incoherence of EU policies causing conflicts in implementation; unequal progress of policies and implementation between member states leading to different needs for support from EU policies; conflicts between economic and environmental

interests; incoherence in regulations between scales; overregulation (Munaretto et al., 2019, referred in Selnes et al., 2019).

Table 3. Factors hindering vertical coherence in policy implementation (Munaretto et al., 2019, referred in Selnes et al., 2019, adjusted)

Administra-tive scale	Vertical coherence issue	Nexus sectors affected	Examples from case studies
EU-national	Implementation of EU directives requires major adjustments of national policy frameworks and infrastructure	Energy	Latvia - The transposition of the EU directive on the promotion of production and use of alternative fuels (2014/94/EU) requires significant, time consuming policy and infrastructure adjustments.
	National measures insufficient or unsuitable to achieve EU targets	Energy	Latvia – Current measures to increase the use of renewables and energy efficiency are insufficient to achieve the EU targets. Latvia – Design and application of national economic incentives for natural gas in cogeneration do not promote energy production from renewable energy sources, thus making it difficult to achieve the EU renewable energy targets. E. Germ-Cz-Slo - Measures taken are not sufficient to reach the EU energy targets within the expected time frame.
	EU energy policy causes conflicts with environmental policy at lower scale	Energy Nature conservation Water Forestry	Sweden – Conflict between Habitat and Birds Directives and bio-energy production targets from forests. E. Germ-Cz-Slo National financial support to the production of energy crops hampers the achievement of EU good water quality objective.
	Conflicts between socio-economic and environmental interests	Forestry Rural economy Agriculture	Netherlands and Latvia - Nature conservation in Natura 2000 is at odds with local economic development. Latvia – National social, economic, and EU driven environmental objectives in forest management can be conflicting, need for better management of trade-offs in forestry management plans. E. Germ-Cz-Slo - Water objectives collide with the interests of other sectors, particularly agriculture.
	Partial or limited support to national regulation by EU policy because: - it is not an EU policy domain; -EU policy put on hold; -national ambitions are higher than EU ambitions.	Energy Agriculture Livestock Soil Landscape Water Forestry Climate	E. Germ-Cz-Slo – The resolution of conflicts between agriculture interests and soil and landscape protection could benefit from the EU soil quality framework directive that has been put on hold. The Czech government uses this impasse to postpone action. E. Germ-Cz-Slo. - The EU water legislation does not address spatial water retention in the landscape, a major problem in the Czech Republic. E. Germ-Cz-Slo – lack of guidance on forestry management due to lack of EU policy framework on forestry. Sweden - the EU climate policy does not fully support the ambitious Swedish emission reduction targets.

			E. Germ-Cz-Slo - The level of animal protection, especially of livestock, established by the EU regulations is considered insufficient by German standards.
	Lack of coordination of implementation actions	Water Climate Energy	Sweden - the Water Framework Directive 2000/60/EC is partially implemented due to limited coordination with the implementation of the directive on flood protection and groundwater directive. Sweden - Lack of coordination between different sectors affects water management. Water authorities do not have much power over forestry authorities and municipalities on water issues. Voluntary collaboration is not sufficient. Latvia - Need for close cooperation and involvement of stakeholders from various sectors to develop national legislation supporting practical implementation of the law requirements to achieve climate targets.
	Lack of clarity of rules in EU policy documents	Nature conservation Agriculture Water Energy (biomass) Waste	Netherlands - Lack of clarity regarding the production and usage of biomass in the EU Natura 2000, CAP, and water policy; no clear and binding sustainability criteria for biomass production. Some biomass is identified as waste for which strict processing and transportation rules apply.
	Lack of communication to affected parties on the provisions of EU and national regulations	Land Nature conservation	Latvia- Insufficient information on new restrictions of land uses, and on the amount and procedure for receiving compensations in Natura 2000 protected areas.
	Overregulation: too many EU rules make EU policy difficult to implement	Nature conservation Agriculture Water	Netherlands - Policies on nature (Natura2000), agriculture (CAP) and water (Water Framework Directive) hard to combine. E. Germ-Cz-Slo – Agri-environmental measures of the CAP: farmers are discouraged to apply for the funds due to the heavy administrative burden.
	Regulations not fully operational because implementation acts are not yet available	Energy	Latvia – Some Latvian energy regulations still miss implementation acts.
	Lack of finances, manpower and capacity for proper management Lack or fragmented knowledge due to poor monitoring and evaluation	Water Forestry	Latvia - Implementation of the river basin management plans stagnates, resistance towards new measures because lack of knowledge about effectivity former actions. Latvia - Need to increase knowledge and capacity of forest owners to take responsibility for sustainable forest management.
	EU regulation implemented to meet minimum requirements with little impact in practice	Agriculture	E. Germ-Cz-Slo. – Greening measures implemented to the minimum, often reported as already implemented practices. E. Germ-Cz-Slo. - Member states can choose the stringency of the GAEC measures under the CAP; implementation in the Czech legislations is voluntary.
	Presence of a complex governance structure with	All nexus sectors	E. Germ-Cz-Slo - Establishment of the EU on top of the German federal structure has slowed down

	multiple administrative levels having responsibility on nexus sectors		and further dispersed responsibility for policy implementation. Diffuse responsibility makes it difficult to identify whether projects should be funded by the national government or the federal states in water management.
National-regional	'Siloed' thinking in policy making and different policy interpretation across scales	All nexus sectors Water	Sweden – "Siloed" thinking can lead to a failure to recognize cross-sectoral issues across different scales. Sweden - Incoherence between national and regional level in how national water regulations are interpreted and enforced by regulators at the regional level.
	Partial or limited support for regional regulation/initiatives by national policy because regional ambitions higher than national ambitions	Energy	Andalusia - Andalusia Energy Strategy 2020 sets more ambitious renewable energy, energy consumption and saving targets than the national law.
	Lack of coordination of implementation actions	Water	Sweden - Lack of coordination between activities for the implementation of the Water Framework Directive. As a result, opportunities for a holistic implementation at regional level are missed.
	Uncertainty about continuity of policy instruments	Energy	Sweden – Policy change can hamper implementation of local policies, e.g. reductions to the feed-in tariff in the energy sector. An additional uncertainty arose because of changes in funding structures associated with the Brexit process.
Trans-boundary	Regulatory differences	Fishery	Upper Rhine - Because of different regulation on fishing season and on the size of fish that can be caught, a fish may be spared on one riverbank, but caught on the other.
	Insufficient sharing of information on planning and management rules for shared resources	Water Energy Agriculture	Upper Rhine - Insufficient sharing of information between the two neighbouring states concerning plans and regulations for the management of shared resources as well as about environmental impact assessments.
	Different natural resource management approaches	Nature conservation	Upper Rhine - The two countries have different nature conservation approaches stemming from their different management experiences.
	Differences in governance structures	Nature conservation Water Agriculture	Upper Rhine – Identification of the right counterpart to interact to, trust building, human resources availability and capacity make transboundary cooperation difficult.
	Lack of financial resources for shared projects or lack of commitment about spending	Nature conservation Water Agriculture	Upper Rhine - Difficulty to obtain financial resources for transboundary projects and research; but also available budget not always fully exploited by eligible partners due to disagreement on project design and implementation.

4.2.2 Incoherence, ambiguities and gaps encountered in policy implementation

Regulatory gaps, ambiguities and implementation barriers were investigated by the ten national, regional and transboundary SIM4NEXUS cases (Munaretto et al., 2019) and summarized by Selnes et al. (2019). The latter categorised the regulatory gaps, ambiguities and incoherencies in policies as follows:

- Conflicting regulations (incoherent objectives and implementation)
- Ambiguous discourses (competing forces)
- Gaps and incoherencies due to a lack of priority (skewed focus)
- Delegated ambiguity (unclear implementation)
- Low awareness of 'Nexus-needs' (neglected sector-crossing solutions)
- Gaps by absent enforcement (no real implementation)
- Ambiguity by diffuse responsibilities (nobody in charge).

The following overall findings derive from the ten SIM4NEXUS national, regional and transboundary cases. The list is not meant to be a complete or exhaustive one because the cases had different approaches and focus. The immense amount of regulations and policies play a role in the ambiguity of policy. Dealing with ambiguity is thus more than just making better priorities through more awareness and willingness.

Table 4. Regulatory gaps, ambiguities and incoherencies in the WLEFC nexus, derived from the ten national, regional and transboundary SIM4NEXUS cases (Selnes et al., 2019, adjusted)

Description	Examples found
Conflicting (incoherent) regulations: between different policy sectors	*Andalusia; Azerbaijan; Greece; Latvia; Netherlands; Sardinia; Southwest England; Sweden; Upper Rhine; Eastern Germany-Czech Republic-Slovakia*
Ambiguous discourses: Two or more dominant and competing discourses, source for inaction, or regulatory gaps due to a lack of common interests.	*Andalusia; Greece; Latvia; Czech Republic; Netherlands; Sweden; Eastern Germany-Czech Republic-Slovakia*
Gaps and incoherencies due to a lack of priority: setting priorities; emphasize on certain elements, others are left out.	*Andalusia; Azerbaijan; Greece; Netherlands; Sardinia; Sweden; Upper Rhine; Eastern Germany-Czech Republic-Slovakia*
Delegated ambiguity: political and high-end administrative policy interests only clear at an abstract level, with unclear implementation.	*Netherlands; Greece; Sardinia; Southwest England*
Low awareness of 'Nexus-needs': no sector-crossing mind-sets, knowledge & coordination missing	*Azerbaijan; Latvia; Sardinia; Upper Rhine, Eastern Germany-Czech Republic-Slovakia*
Gaps by absent rules/enforcement	*Sardinia; Upper Rhine; Eastern Germany-Czech Republic-Slovakia*
Ambiguity by diffuse responsibilities: Nobody responsible and the result is ambiguity and inaction.	*Azerbaijan; Latvia; Sardinia; Upper Rhine*

4.2.2.1 Incoherent regulations between different policy areas

Many policy incoherences manifest in practice during implementation. In *Andalusia* there is a conflict between water efficiency and energy use in modernised irrigated agriculture. *Azerbaijan* faces

conflicts between economic interests (export and domestic use of locally extracted oil and gas, and climate goals). *Greece* has conflicts between agricultural policy (CAP), that subsidizes the growth of water intensive crops (cotton), and water policies that intend to reduce the pressure on water resources. In *Latvia* there are conflicts between renewable energy (wood, hydro-power, bioenergy crops), that helps to achieve the objectives of renewable energy, but has negative impacts on water, and aquatic and forest ecosystems. Also, energy crops production in monocultures conflicts with food production. Logging also goes against environmental policies. *The Netherlands* faces conflicts between biomass as an energy source and higher-end usage, for example in the chemical or pharmaceutical industry. The use of rest streams for energy generation conflicts with carbon sequestration and resource efficiency in agriculture, and protection of forests and biodiversity in natural and agricultural areas. In *Sardinia,* the expansion of irrigated agriculture demands much water which counteracts the policy to reduce water consumption, and the nature protection regulations. *Southwest England* is dealing with many conflicts, between water and agriculture policies due to disparities between regulations for point discharge of wastewater and diffuse pollution from agriculture. Also, stimulating bioenergy is incoherent with agriculture and environmental regulations, and with soil protection, abating soil degradation and erosion. Waste regulations conflict with renewable energy targets. In *Sweden,* the market-oriented agriculture and forestry are incoherent with environmental protection (biodiversity) and water quality. The *Upper Rhine* has incoherencies caused by overexploitation of forests and conflicts between agricultural production and nature protection. The *Eastern Germany-Czech Republic-Slovakia* transboundary case experiences conflicts derived from biofuel production, such as incoherencies in the regulations for land-use, biofuel for energy, agriculture for food, water and environment. Also, conflicts between wind energy and land-use is an issue in Eastern Germany. Incoherencies between landscape, soil, water, energy and environmental protection are reported to be present in the *Czech Republic*. For *Slovakia,* we see incoherencies in the regulation of energy, biofuel and agriculture.

4.2.2.2 Ambiguous discourses

Policy is not a 'neutral' activity. Of paramount importance for the regulatory practice are discourses that work against each other. At the basis of most conflicting discourses is the clash of interests between economy and environment. These competing discourses fuel conflicts for example between agriculture, forestry and energy policies on the one hand, and environmental policy on the other hand. Environmental interests are mainstreamed in these basically economic policies, but this does not solve the problem of conflicting interests. The cases demonstrate the commonality of ambiguous discourses, which have effects on how policy is made and conducted.
In *Andalusia,* increased economic activity and development hamper preservation and protection of natural resources as well as reduction of greenhouse gas emissions. In *Azerbaijan,* ambiguous discourses stem from the conflicting interests between the economic importance of fossil fuels against the need to increase the share of renewable energy. *Greece* reports on ambiguities between economic and sustainability discourses in the energy versus climate debate and agriculture versus reducing water use. In *Latvia,* conflicting discourses are found in forestry versus sustainability. In the *Eastern Germany-Czech Republic-Slovakia* transboundary case, there are conflicting discourses between large-scale monoculture agriculture and landscape protection and restoration. *The Netherlands* reports on competing discourses between biomass for energy generation versus a resource efficient economy with high value usage of biomass, protection of forests and biodiversity, and food security. There is a vehement debate between those who think that woody biomass reduces greenhouse gas emissions and those who believe the opposite. *Sweden* reports on disparity between intensive agriculture and forestry, and protection of environment and nature.

4.2.2.3 Gaps and incoherencies due to a lack of priority

The lack of priority follows the distribution of power within the Member States and EU. In general, minor priority for sustainable solutions seems to play a role in various cases, for example in the use of water and land in *Sardinia*, agri-environmental measures in *Sweden*, soil management in *Upper Rhine*,

and also in the commitment to sustainability in the *Eastern Germany-Czech Republic-Slovakia* transboundary case. In *Andalusia,* promoting clean (renewable) energy does not have priority. *Azerbaijan,* whose economy depends on exporting oil and gas, is facing a similar situation. In *Greece*, agriculture production and tourism prevail above sustainability policies. *Latvia* reports a lack of priority for environment and biodiversity, for example in forestry. In *The Netherlands,* officials noted that climate now receives more attention than a broader resource efficiency approach.

4.2.2.4 Delegated ambiguity

A special case of ambiguity derives from policies that turn out to be unclear in the practical usage during implementation. We see this in *The Netherlands,* where the policies for biomass usage in the business chain are far from clear. We also observe this from the *Greek* case with the policies for irrigation and use of pesticides in agriculture, in the biomass value chain in *Sardinia*, and the regulation for wastewater in *Southwest UK*. It hampers efficient implementation and is related to lack of priority, incoherent regulations, ambiguous discourses, and diffuse responsibilities.

4.2.2.5 Low awareness of 'nexus-needs': no sector-crossing mindset

In many cases there is low awareness of any need for sector-crossing knowledge and coordination. We see this for example in the cases from *Azerbaijan, Latvia Sardinia, Upper Rhine, Eastern Germany-Czech Republic-Slovakia.* We do believe the awareness in all cases varies and that it is hard to point to a certain level of awareness. But the issue does deserve attention when it translates and affects policy achievements. Also, see Chapter 4 about policy governance.

4.2.2.6 Gaps by absent rule and enforcement

Absent rules or rules that are not enforced probably are common in many settings. We have observed here some examples of this situation. In *Sardinia* we see this in missing incentives to enforce rules in land-use, water and agricultural policies. In *Upper Rhine*, the French biodiversity law is not in use. *Eastern Germany* has enforcement issues in climate and environmental policies and the *Czech Republic* in management plans for water, agriculture, with no regulation for groundwater. Agro-environmental measures are not or hardly implemented. A more general challenge is the absence of soil protection policies where the Member States do not want any EU-policy on soil.

4.2.2.7 Ambiguity by diffuse responsibilities

In general, nobody is responsible for the whole WLEFC nexus. Implementation situations where nobody really is responsible for a certain policy part is observed in *Azerbaijan*, where there are many policy actors with regulatory authority, and in *Latvia* with the issuing of permits for and enforcement of land management. We see it in the land-use enforcement and responsibility for water management in *Sardinia* and for the responsibility for the overall strategic plan in *Upper Rhine*. This list is likely to grow if it is investigated more in detail.

4.3 Recommendations for coherent and relevant policies through a WLEFC nexus lens

*..... the Commission and Member States should work to ensure that all available planning tools for the European Green Deal are used coherently. The most important of these are the national energy and climate plans and the proposed strategic national plans to implement the common agricultural policy (*European Commission, 2019a).

4.3.1 Political will, nexus-oriented mindset and long-term scope needed

The European Green Deal and follow up actions show a fundamental system approach. SIM4NEXUS recommendations intend to support this system thinking by suggesting integrated and synergetic strategies, stimulated by coherent policies for the WLEFC nexus components. The extent to which the European Green Deal will be accepted, and the detailing and implementation of its follow-up plans will

determine its outcome and impact. Therefore, political will and mindset are necessary to broaden the scope beyond the usual sectoral perspective and put the long-term interest of a sustainable future above short-term profit. This also applies to the implementation. Rules must be set and enforced, supported by necessary resources, and responsibilities must be clear, also for cross-sectoral issues. According to the *Sweden* SIM4NEXUS case, for example, there is a need for support from the EU legal framework to be able to introduce stronger national regulations. Particularly, the environmental aspects need to be strengthened, such as biodiversity conservation or development of green infrastructure for increased climate resilience.

4.3.2 Support change in consumption behaviour to reach maximum synergy

SIM4NEXUS model results for food, energy and water indicated that the most cost-effective and synergetic interventions in the WLEFC nexus are related to changing consumption behaviour and, second best, increasing resource efficiency, because these strategies reduce resource demand. According to the principle of 'Upstream thinking (section 3.3.1), cost-effectivity and synergy are highest in the order of 1. Change consumption behaviour to decrease demand, 2. Increase efficiency to reduce resource use and emissions, 3. Meet remaining and potentially growing demand with renewable natural resources, investing in more sustainable production methods to reduce environmental impact of supply. A further investigation of the validity of this 'Upstream thinking' principle in different situations is recommended. If it has a widespread validity, it could refresh viewpoints and lead to new narratives and policies for a combined resource efficient and low-carbon development.

4.3.2.1 Stimulate diet change

A combination of diet change and resource efficiency in the food chain combined with food waste reduction has multiple benefits and is the most synergistic policy in the WLEFC nexus according to modelling results(section 3.3.1.2; Global and Europe cases in Brouwer et al., 2020). Stimulating a diet change is part of the 'From Farm to Fork' strategy. Reducing food waste is already a broadly addressed issue in European and national policies. The new challenge will be to develop policies to implement a diet change. Developing a policy framework and policy instruments to stimulate a healthy and more plant-based diet for consumers at European scale is relevant, coherent and has added value, because 1. diet-related diseases are a widespread health problem, 2. production of animal-based food has huge environmental impact in and outside Europe, 3. a move to healthier and more plant-based diets is the most synergetic pathway to reach all goals for the WLEFC nexus, and several goals of the 'From Farm to Fork' strategy, 4. it is practical to have common standards and information about healthy food for all consumers, suppliers and producers in Europe. Effort must be put in educating people and investigating factors that make people keep or change their behaviour and consumption. Trade-offs to livestock farmers and other businesses linked to animal-based food must be acknowledged and addressed to support the transition.

4.3.2.2 Decrease energy demand and increase efficiency

At European level, policies to reduce energy use seem to be focused on increasing energy efficiency in the total energy chain, and supporting consumers to choose more energy efficient electric devices. Reducing energy demand by changing consumer behaviour per se is not addressed. Education to change consumer behaviour is usually left to energy suppliers and NGOs. However, according to the European Commission (2019f), progress in achieving the 2020 energy targets (share of renewable energy, energy efficiency, greenhouse gas reduction) has been slowing down due to the increasing energy consumption trend since 2014, partly because of insufficient measures implemented at national level. It seems worthwhile to investigate if, - in addition to energy efficiency policies-, policies should be developed at national and European scales, targeted at changing consumer behaviour to reduce energy demand, without increasing energy poverty. This strategy could reduce the demand for other resources as well. Stakeholders in the *Upper Rhine* SIM4NEXUS case found that energy transition

focused too much on its technological dimension. There is a need for change in the policy focus: energy efficiency gains and especially energy savings and decrease in energy consumption should be prioritized (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020). Trade-offs to those businesses that depend on unsustainable consumption behaviour must be acknowledged to support a smooth transition.

4.3.2.3 Decrease water demand and increase efficiency

Water efficiency in agriculture and other sectors is a common issue in resource efficiency policies. Campaigns about water footprints of consumption have been going on for more than a decade by NGOs, universities, and UNEP. Campaigns by water companies and water boards for economical water use pop up with every period of drought. Similarly to energy use, it seems worthwhile to investigate if policies should be developed at national and European scales, targeted at changing consumer behaviour to reduce water demand and water footprints.

4.3.3 Improve coherence between WLEFC policies and exploit synergies

4.3.3.1 Mainstream nexus approach in policy output, impact assessments and evaluations

In general, policy documents for different WLEFC nexus components could refer more to each other, and have a more systemic, cross-sectoral view, pointing out linkages, synergy and trade-offs between the policies and higher-level goals to be reached for the whole system (Munaretto et al., 2017 and 2019). The development of nexus-compliant policies could start with a broad inception impact assessment from a nexus viewpoint, that makes an inventory of potential cross-sectoral linkages with the new policy initiative, in addition to investigating the potential impacts on environment, society and economy. Knowledge could be built up from monitoring and evaluation of policy impacts from a broad nexus viewpoint, tracing cross-sectoral trade-offs and synergies.
Selnes et al (2019) recommends to compare and share experiences with conflicting EU and national regulations, facilitate solutions to solve these conflicts and seek for opportunities offered by synergy between regulations. Also, they recommend spreading out successful nexus implementations and ensure that these are scaled up in Europe.

4.3.3.2 Address trade-offs and exploit synergy between resource efficient and low-carbon pathways

Mutual trade-offs between low-carbon and resource efficient pathways must be assessed and avoided, and options to capture synergy between these pathways assessed and captured, as is also mentioned in the New Circular Economy Action Plan (European Commission, 2020b). Life cycle analysis (LCA) seems to be an essential part to reach both goals together. The suitability of LCA to address this challenge must be assessed and if necessary improved.

4.3.3.3 WLEFC nexus recommendations for the revision of the Renewable energy directive (REDII)

As a follow-up of the European Green Deal, the Renewable Energy Directive (REDII) will be revised to upgrade the 2030 greenhouse gas reduction target and reach climate-neutrality in 2050. The revision initiative will look at the establishment of 'a comprehensive terminology and robust certification system [for renewable fuels] including associated greenhouse gas and sustainability criteria, based on a robust life-cycle approach and traceability system' (European Commission, 2020i). The initiative also intends to look at *'the sustainability and greenhouse gas emissions saving criteria for bioenergy ..... and terminology and certification of fuels'*, and *'The risk of unintended incentives for using unsustainable biomass will be assessed and minimised through appropriate safeguards'*. The initiative addresses the widespread concerns about trade-offs from renewable energy to natural resources, forests and other ecosystems, food security, climate and environment.

SIM4NEXUS results lead to the following recommendations for the revision of REDII:

- The cross-compliance and greening conditions in the CAP could also count for energy generated from crops that Member States can count towards their national targets when calculating the national share of renewables.
- Sustainability criteria for biobased energy resources from Europe as well as abroad, should become more transparent, verifiable, and strict. This may also improve the bad image of biomass and bioenergy from food and feed crops. Sustainability criteria for biodigesters must be specified.
- Policies that stimulate the use of renewable energy, especially bioenergy, should only be put in place, if potential negative effects on environment and food security, as well as climate neutrality are assessed and avoided or mitigated.
- The effects of increasing the use of bioenergy on food security and food prices should be better addressed. It must be clear how the European Commission will monitor these effects and what concrete actions will be taken if unwanted effects are observed.
- Do not stimulate the installation of scattered small-scale bioenergy plants.
- Impacts from renewable energy generation on water quantity and quality, as well as impacts on hydrological cycles, must be better addressed and more strictly regulated. This cannot be left to voluntary schemes. Also, the dependency of renewable energy generation on water availability and negative effects of competition for water in case of scarcity, should be assessed and addressed in the context of climate change. This would count e.g. for hydropower and bioenergy crops.
- Trade-offs of large-scale monoculture in agriculture to the landscape and soil, hydrological cycle, local climate and adaptation capacity, should be addressed in the REDII (bioenergy crops) as well as the CAP.
- The use of biobased natural resources for energy generation must be weighed against higher value use in the biobased economy, as sustainably produced biobased resources will probably become scarce.

Other recommendations for renewable energy, made by SIM4NEXUS cases are:

- Stricter regulation for land take and environmental impacts by bio-energy crops and solar farms (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020). This goes well with the Farm to Fork strategy to place solar panels on farmhouses and barns and prioritise such investments in the future CAP Strategic Plans. In general, address competing claims on land and water for food, feed, fibre and bioenergy crops.
- Stimulate innovation in bioenergy generation, sources, use and efficiency (Southwest UK and Latvia SIM4NEXUS cases in Brouwer et al., 2020).
- Strengthen and develop transboundary cooperation on energy policy (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020).

4.3.3.4 WLEFC nexus recommendations for the revision of the CAP

The proposals for a new Common Agricultural Policy (CAP) for 2021 to 2027 "aims higher" regarding the environment and climate (European Commission 2019e). Stricter environmental conditionality for receiving CAP payments, and new eco-schemes funded under Pillar I are intended to stimulate sustainable agricultural practices. The Water Framework Directive and the Directive on the Sustainable Use of Pesticides will enter the scope of conditionality and new standards for good agricultural and environmental conditions (GAEC) will be introduced.

The CAP revision offers the opportunity to mainstream WLEFC nexus thinking, as it is relevant for all nexus sectors (agricultural food production, bioenergy production, biodiversity conservation, adaptation to climate change and improving climate resilience, climate change mitigation, as well as water management).

Recommendations stemming from SIM4NEXUS results are:

- Support farmers in the transition from livestock to horticulture and arable farming, and stimulate the growth of crops that deliver plant-based proteins (Global and Europe SIM4NEXUS case in Brouwer et al., 2020).
- Stimulate new, innovative business models for sustainable farming combined with deliverance of ecosystem service and public services, to increase and secure farm incomes.
- Support farmers to adapt to climate change.
- Take local and regional climate change caused by degradation of the agricultural landscape and disturbance of the hydrological cycle seriously, and investigate occurrence and extent within Europe. Stimulate the restoration of the landscape and hydrological cycles, and soil-conserving agriculture. Include the restoration of the agricultural landscape and hydrological cycles in the CAP strategic plans by the Member States, where appropriate. Include good management practices of soil and water in the CAP. All this can very well go together with multifunctional agriculture, organic farming, production of local food, payment for delivering ecosystem services, increasing natural areas and forests. These measures also serve the long-term continuation of high productive farming.
- Support multifunctional agriculture that produces food and energy, supports biodiversity and climate resilience.
- Bridge the controversy between economic and ecologic interests in agriculture and the CAP, by developing new narratives about the short-term and long-term shared interests and profits.
- As implementation of policies for water quantity and quality need a boost, include cross-compliance with the Water Framework Directive in the CAP, as suggested in the current proposals, as this would help to protect and improve water quality. Cross compliance with water quantity targets, for example keeping minimal ecological flows, could also be included.
- Nature-based solutions are already high on the European agenda for urban areas. Put nature-based solutions higher on the policy agenda to solve water and soil problems in agricultural rural areas.
- The proposal for the CAP revision to set stricter greening conditions for payments is supported, as well as better implementation and enforcement in the Member States, for example the standards for Good Agricultural and Environmental Condition (GEAC) (Eastern Germany-Czech Republic-Slovakia and Andalusia SIM4NEXUS cases in Brouwer et al., 2020).
- Stimulate the growth of less water-demanding and climate change resilient crops. Increase diversification of crops (GREECE, SWEDEN). The Mediterranean cases suggested to put a maximum on irrigated area and water withdrawal, as one of the conditions of financial support (Andalusia, Sardinia and Greek cases in Brouwer et al., 2020).
- Stimulate efficient irrigation systems that do not need extra energy to function, stimulate sensor-based irrigation. Such technological improvement could not only reduce water demand but also reduce fertilization requirements, with benefits for the environment by reducing nutrient loads to water bodies and economic benefits for the farmer (Upper Rhine, Sardina and Greece SIM4NEXUS cases in Brouwer et al., 2020).
- Use the CAP strategic plans and eco-schemes financing options to support the growth of forests. This will restore hydrological cycles, support climate mitigation and adaptation, buffer heat waves, droughts and floods. Forests can produce biomass and increase biodiversity in the agricultural landscape.
- Be prudent with stimulating biodigesters on farms, as there may be many negative impacts, such as competition for land between energy crops and food and feed crops, monocultures, increased use of fertilizers and pesticides, land left bare and subject to soil erosion, potential conflicts with agro-environmental schemes, land becoming over-priced, subsidies granted without questioning the efficiency of this way of energy generation or energy use, loss of methane, doubts that this way of energy generation is driven by demand or subsidies.
- Reduce the administrative burden of financing schemes.

- Use CAP more actively to create synergy between water management, agriculture, sustainable production of energy and nature protection and development. Open CAP for other actors than farmers (Netherlands SIM4NEXUS case in Brouwer et al., 2020)
- Base CAP financing on delivered services instead of hectares and production.

Other recommendations for agricultural practices, made by SIM4NEXUS cases are:

- A nature inclusive agriculture is in the best interest of both nature and agriculture. To reduce the conflict between nature and agriculture it is good to focus on the synergies between the two of them and explore the possibilities for better integrated policies. Sustainable biomass production could play a role in such a process (Netherlands SIM4NEXUS case in Brouwer et al., 2020).
- Sweden could better promote and utilize its image of environmentally friendly food producer and build its market competitiveness on it. This would lead to better alignment of the agricultural goal with other goals, particularly environmental objectives.

4.3.3.5 WLEFC nexus recommendations for water policies

- Better define and regulate Minimum Environmental Flows (MEF). This will have effects on land and food components of the nexus (Sardinia SIM4NEXUS case in Brouwer et al., 2020).
- Synergies can be created by integrating land use and water management. Upstream catchment management and paid ecosystem services, for example, can improve surface water quality and reduce the energy demand of drinking water treatment. This could involve the restoration of peatland and improving farming practices for the potential benefits of surface water quality and biodiversity (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

4.3.4 Improve data access and database interoperability between policy areas

Install a policy that regulates data access and database interoperability to coordinate cross-sectoral data exchange, both horizontally and vertically. The policy recommendation targets at national government and regional authorities and agencies. However, a framework directive at European scale could support this action and support cross-border data exchange (Sweden SIM4NEXUS case in Brouwer et al., 2020).

5 Policy governance through a WLEFC nexus lens

Governance is the sum of the many ways individuals and institutions, public and private, manage their common affairs' (Commission on global governance, 1995). Policy governance concerns all actions that are part of policy making, implementation and evaluation, the way actions are organised with formal and informal arrangements, who is involved, responsibilities and competences.

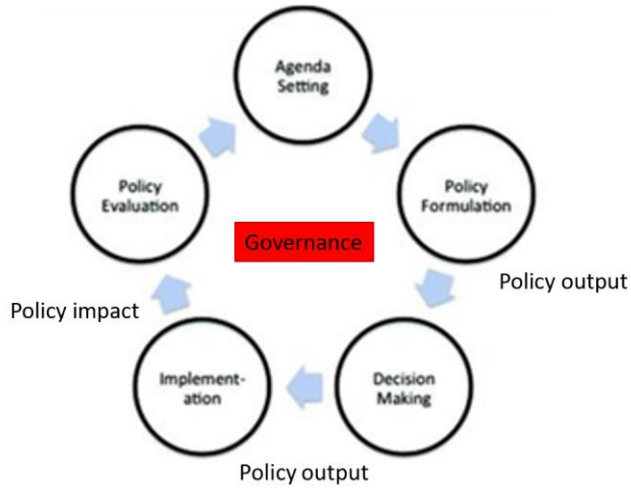

Figure 6. Position of governance in the policy cycle

A policy process is ideally a combination of a scientific, and political process, with multiple exchange of knowledge, questions, visions and insights between the two, in both ways and during the whole process. Figure 7 illustrates how the scientific and political processes interact in all phases of the policy cycle (Witmer et al., 2018). Ramos et al. (2020), in interaction with the SIM4NEXUS cases, developed a 'SIM4NEXUS Assessment Framework' for the scientific process to investigate the WLEFC nexus.

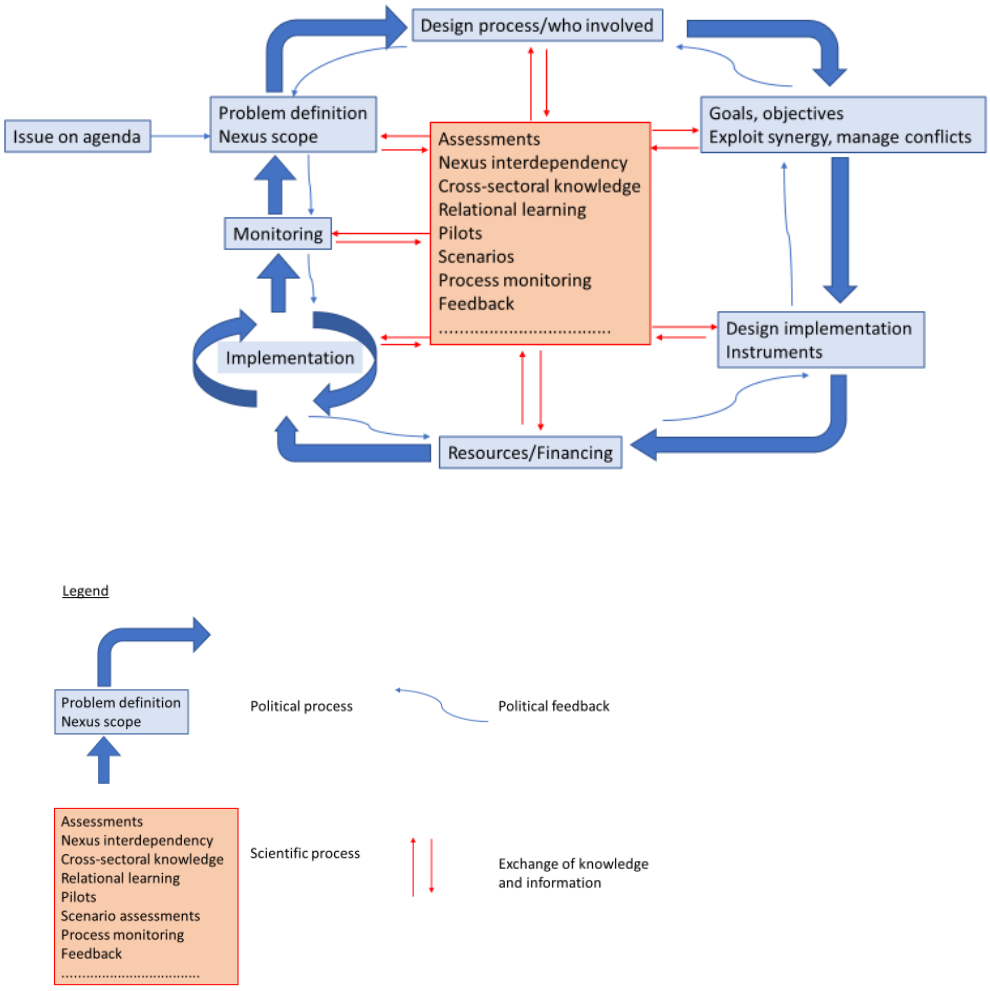

Figure 7. Scientific and political nexus policy processes, interacting in the policy cycle (Witmer et al., 2018)

5.1 Success factors for nexus governance and policy process

The extensive list of success factors for governance of nexus policy processes is based on literature about principles of good governance, among others developed by the European Commission (European Commission, 2011), an analysis of eight cases dealing with integrated resource management from different countries worldwide with different management approaches (Svensson, 2018), and information provided by the national, regional and transboundary SIM4NEXUS cases. Implementation of these success factors should be tailor-made, appropriate for the issues at stake and stakeholders involved. Success factors do not stand alone but are interrelated. The case studies show many examples of national and regional tailor-made solutions that are successful but not necessarily common practice yet. Success in a nexus policy process depends on multiple factors. Factors that are successful in one setting might not have the same effect in another where the culture of interaction might be different. The context and timing are decisive for success (Selnes et al., 2019).
As the list of success factors is extensive, the question arises when nexus governance is 'good enough' in practice, to make implementation realistic. This must be explored by applying the success factors in practice (Witmer et al., 2018).

Table 5. Success factors for governance of a policy process through a nexus lens.
(Witmer et al., 2018, adjusted)

GOVERNANCE

CROSS-SECTORAL AND CROSS-SCALE KNOWLEDGE MANAGEMENT AND RELATIONAL LEARNING

Generation and Integration of different types of information

* Understanding interconnections (biophysical, socioeconomic, governance) between nexus components and scales
* Generation of cross-sectoral and cross-scale knowledge based on understanding of interconnections between nexus sectors and scales where influences manifest

Relational learning

* Knowledge sharing across stakeholders, DGs, ministries, research areas, governance levels
* Trust between stakeholders
* Understanding of diverse perspectives and interests
* Common language and definitions
* Awareness of interdependency

DEALING WITH UNCERTAINTY AND COMPLEXITY, ALSO CROSS-SECTORAL

Uncertainty

* Acknowledge and accept unpredictability
* Integrate adaptability and flexibility in planning to change with circumstances, and new insights and knowledge
* Allow for experimentation, within limits
* Consider multiple possible scenarios for long-term governance planning, including a baseline scenario

Complexity

* Investigate and take into account:
  - feedback loops
  - time lags
  - different sectors and scales

MULTI-SECTORAL SOCIAL DYNAMICS AND PARTICIPATION

Visioning

* Political and societal willingness to cross sectors, cross institutional silo's, by education, thinking in nexus
* Common understanding of problems, needs, solutions, goals
* Ownership of and commitment to nexus approach

Cross-sectoral and cross-scale cooperation with fair and equal power relations

* Leadership that builds bridges between sectors, perspectives and scales
* Inclusion of all stakeholders from all nexus sectors and representation of all interests
* Fairness among stakeholders and nexus sectors
* Equal priority to all nexus sectors
* Responsiveness to stakeholders of all nexus sectors
* Do not leave issues unresolved
* Avoid high turn-over of staff

Legitimacy

* Build on established framework
* Authority to make decisions
* Support from Government, legislation, higher authority

* Public awareness
*Transparency for insiders and outsiders of process, progress, vision, goal
* Accountability
* Fair rule of law

RESOURCES, ALSO FOR THE 'IN BETWEEN' AND 'TOTAL' OF THE NEXUS
* Clearly and fairly allocated financial and human resources to support the nexus approach
* Fair and clear distribution of costs and benefits
* Long-term support for nexus policy making, implementation, monitoring and evaluation
* Clear and flexible progressive implementation guidelines and clearly defined responsibilities, tasks and roles
* Capability and education of actors to boost the change and to change own behaviour

MONITORING AND EVALUATION, ALSO SYNERGIES AND TRADE-OFFS
* Agreed upon, representative and measurable progress indicators for all goals and objectives in the nexus
* Monitoring and evaluation of trade-offs and synergies, at the scale, in the region, at the actor where they manifest
* Well-functioning monitoring, evaluation and reporting

5.2 Recommendations for nexus governance: knowledge-based, inclusive, and supporting

'*It will require intense coordination to exploit the available synergies across all policy areas.*'
*'Stakeholders to identify and remedy incoherent legislation that reduces the effectiveness in delivering the European Green Deal' (*European Commission, 2019a).
'..meaningful collaboration will require increased time, expertise, understanding and coordination.' (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

5.2.1 General recommendations

Nobody is in charge of the whole WLEFC nexus. Therefore, cross-sectoral cooperation is always part of a nexus policy process. Political, mental and institutional silo's need to be bridged (Niestroy and Meuleman, 2016). Currently, interlinkages between WLEFC sectors are not reciprocally and equally addressed. More powerful, driving sectors, such as energy, forestry and agriculture, tend to have less eye for nexus relations and trade-offs than less powerful and affected sectors such as water and land management and nature protection. In a market economy, the financial capital is overvalued, the human capital is undervalued, and the natural capital is not valued (Selnes, 2020b). In this context of conflicting interests, the optimal state of the nexus is a political choice and not the outcome of a technical calculation. The same is true for the pathways that lead to the optimal state, they are political choices, outcomes of weighing conflicting interests in the context of autonomic socioeconomic and ecological developments and unforeseen events. Coherent, balanced, inclusive and fair nexus pathways to reach the goals of the European Green Deal will only be possible in a process with equal power relations between the sectors involved. This would mean a turning point in the business as usual policy processes. Broad commitment and ownership will be needed, derived from a shared vision on the problems and goals. Potential shared benefits and common interests must be investigated and communicated in messages that resonate with the audience, and obstacles and objections stemming from conflicting interests and viewpoints must be assessed and taken seriously (Selnes, 2020b). Therefore, participative processes from the beginning till the end are crucial.
The European Green Deal and Horizon Europe have incorporated system thinking, without calling it a nexus approach. Policy making seems to develop into a more transversal direction.

A nexus policy process is multi-scale, multi-sector and multi-actor and concerns the whole policy cycle, from the very start, the agenda setting, till the very end, the evaluation leading to an update of the agenda. A balance must be found between capacity and time investment in the process and added

value. However, only with broad ownership and commitment, the ambitious goals of the European Green Deal can be reached. Therefore, it seems worthwhile to invest in a multidisciplinary participative process during the whole policy cycle. Commitment can be hard to achieve as it easily might be seen as a loss to strongly sector-based silos of power. Dialogue with sectors is then of importance, but also the will and ability to force change, if necessary. A balance must be found between regulatory gaps and overregulation. As Member States differ widely in governance, priorities, and progress in implementation, there is not one solution for this problem.

New integrating themes stimulate a nexus approach, as is already started to be applied in the From Farm to Fork strategy. Another broad theme could be 'Stay within planetary boundaries with a globally equal and fair share of resources, combined with a resource efficient and low-carbon development'. These nexus themes that cross the boarders between policy fields and scales, may be institutionalized to change views from sectoral to transversal. To keep flexibility and avoid new silos, a balance must be found between temporariness of the new organisation and time needed to create cross-sectoral expertise and understanding of different viewpoints.

5.2.2 Cross-sectoral and cross-scale knowledge and relational learning

The exchange of knowledge and capacity building are important for the innovation of the project, the equity of participation and the achievement of goals. Knowledge that is available may be contested and debated. For example, the *Latvia* and *Netherlands* SIM4NEXUS cases mentioned the debate about biomass production. The discussions were silos-based and polarized between different discourses. Scientific knowledge is subject to debate because of different interpretations (Netherlands and Latvia cases in Brouwer et al., 2020). It is important that parties are open to different interpretations and framings of knowledge. Specific for a nexus, involving many sectors means that learning about new methods, languages and jargons will be necessary. It is also important to raise awareness about issues in different sectors that might not be known by stakeholders in other sectors (Selnes et al., 2019). The European Commission (2017b) also mentions peer exchange as an important means to improve mutual learning and expertise and to make sure that tested solutions are passed on to others. Several SIM4NEXUS cases mentioned little exchange of information and communication between decision makers of different sectors, and a lack of cross-sectoral knowledge, data and knowledge about nexus linkages, and missing, inaccessible and incomparable data as a big problems (Brouwer et al., 2020).

SIM4NEXUS recommendations:

- Organise mutually exchange of knowledge and insights between and within the science and policy processes during the whole policy process.
- Assign an important role to social sciences in the scientific process, as changing behaviour is important for the transitions needed to reach the ambitious goals of the European Green Deal.
- As science is contested, meetings between stakeholders with opposite viewpoints that adhere to different discourses must be facilitated repeatedly, to create and keep understanding for different interpretations and framings.
- Facilitate the exchange of knowledge and insights with tools such as serious games, tailor-made, clarifying and attractively visualised information, and process supporting tools such as Joint Fact Finding.
- Make nexus and coherence assessments part of inception impact assessments to define the nexus scope of the policy-making process and decide about disciplines and stakeholders to be involved. Check and adjust the scope during the policy process, because of advancing insights.
- Develop a framework, including definitions, to make data between policy fields and scales mutually comparable. Make data open access and easy to use. Develop a database of quantified nexus connections.

- Involve stakeholders in the development of scenarios and assumptions underlying models.
- Besides top-down, also use bottom-up approaches to create local awareness, increase acceptance especially if measures concern habits and routines, learn about local needs and gather local knowledge.

Textbox 1

Bottom-up process stimulated relational learning in Slovakia and the Czech Republic

The *Eastern Germany-Czech Republic-Slovakia* transboundary SIM4NEXUS case was successful in sharing knowledge and raise awareness in a bottom-up relational learning process with government officials, politicians, NGOs, farmers, research institutes, land owners and other stakeholders. Research institutes and NGOs acted at regional level with direct contact to decision makers and politicians. They invited them to many lectures and discussions about landscape degradation. The fact that during the last several years periods of drought got longer and more intense, helped to convince people of the severity of the situation and the need to find asolutions for these problems and implement them. Interactions with local stakeholders was helpful for understanding the system. Everybody learned from each other. It was often not easy and took time to deepen a contact to a point where detailed insights from someone's field of experience were freely shared. In a couple of cases, personal trust was built, and these contacts became lead to the most interesting and valuable exchanges with stakeholders. The nexus approach shaped learning and awareness of the connections between sectors. It stimulated discussions and urged everyone to take a step back and look at the situation from a broader perspective (Eastern Germany-Czech Republic-Slovakia transboundary SIM4NEXUS case in Brouwer et al., 2020).

5.2.3 Dealing with uncertainty and complexity, also cross-sectoral

A nexus approach deals with many uncertainties, and scenario building has been shown to be an efficient way to increase the awareness of issues and prepare stakeholders for uncertainties, making the project more resilient. A broadly accepted scientific baseline is a good start of the combined scientific and policy process. Developing the baseline should be given sufficient time, as a thorough understanding of the interconnections between resources and sectors is crucial. Moreover, no improvements can be measured without setting the baseline (Selnes et al., 2019).

Adaptability needs to be acknowledged already in the planning phase to prepare stakeholders and players that change may happen along the way. Revision of targets or methods to incorporate change will most likely be necessary, because governing a nexus involves many uncertainties (Selnes et al., 2019). The *Southwest UK* SIM4NEXUS case mentioned as a valuable lesson the ability to respond quickly to any unforeseen consequences in enacting a policy, recognizing that not all outcomes can be predicted and acknowledging that altering policies is not the sign of a failed strategy, rather the outcome of an open and innovative mind (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

Segmentation of responsibilities are mentioned as complicating factor by the *Andalusia* case. While the promotion of renewable energy depends mainly on national decision making in Spain, sustainable water management is a challenge that is mainly addressed by regional policies. This situation limited the promotion of renewable energy and sustainable water management in the region (Andalusia SIM4NEXUS case in Brouwer et al., 2020).

SIM4NEXUS recommendation:

- Plan for adaptability and allow for objectives and targets to be revised to keep them relevant. Acknowledge this already in the planning phase to prepare stakeholders and players that changes may happen along the way.

5.2.4 Multi-sectoral social dynamics and participation

5.2.4.1 Visioning

A shared vision on the problems that need to be solved, the goals to be aimed for, and the need for a cross-sectoral approach, is at the centre of a nexus policy process. This vision is not static, but will change with new insights, increasing knowledge, and better understanding of different viewpoints. Also, new developments in society may change visions. Therefore, visioning is a continuous process and viewpoints must be repeatedly shared and checked. Creating ownership of the project can increase the likelihood of it being sustained in the future.

According to the *Sweden* and *Upper Rhine* cases, it is important to introduce nexus related environmental aspects early in education systems to create a society that is aware of and can deal with environmental problems. Increasing capacity of the general society about nexus challenges can lead to social innovations that will iincrease chances to deal with these challenges. Including nexus thinking form the early stages of education will support development of a new generation of experts for whom the nexus interaction will be an obvious thing and who will be able to work in an integrated manner (Sweden and Upper Rhine SIM4NEXUS cases in Brouwer et al., 2020)
According the the *Southwest UK* case, embedding nexus thinking into research, business and policy spheres needs to happen to help unify global challenges and provide coherency in aims within and between countries. Knowledge regarding the benefits, costs and challenges involved in nexus compliance is increasing, but solutions around how to operationalise nexus thinking on the ground are still lacking. There is consensus about the need for nexus thinking in policy making, yet how to 'bind or tie' the sectors together to increase cooperation, coordination and policy coherence is not straightforward. It must be noted that meaningful collaboration will require increased time, expertise, understanding and coordination (UK SIM4NEXUS case in Brouwer et al., 2020).
The *Europe* case proposes a dialogue inside and between DGs of the European Commission, and with the Commitee of the Regions on how to deal with land-use changes because of possible changes in diets or increasing land destined for energy-crops and solar farms. Also, they advise to conduct an early dialogue on societal effects of the low-carbon and resource efficiency transition (Europe case in Brouwer et al., 2020).

SIM4NEXUS recommendations:

- Start educating children early in school programmes to raise awareness, enable transdisciplinary and cross-sectoral cooperation and 'eliminate' silo-thinking., for example by letting pupils and students work on interdisciplinary themes.
- Viewpoints must be repeatedly shared and checked, as visioning is a continuous process.
- Organise discussions about the societal effects of the low-carbon and resource efficiency transitions, and about land-use change caused by the increase in renewable energy and decrease of consumption of animal-based food.

5.2.4.2 Cross-sectoral and cross-scale cooperation with fair and equal power relations

For a nexus approach, involving stakeholders from all relevant sectors in every aspect and phase of the process is crucial. Involving local communities can be an efficient way to get information about local policies, cultures and knowledge, and avoid conflicts. Involvement can also increase ownership. A high staff turnover should be avoided to minimise the loss of information, legitimacy and emotional connection with the project (Selnes et al., 2019, adjusted).
Subsidiarity is an important criterion to divide the decision and implementation power. Decision and implementation power should be awarded to the most local level possible, to assure that correct information is used, to create ownership and acceptance and to avoid conflicts with local or regional plans and regulations. Regional or national leadership should be used when local leadership does not

have sufficient capacity. Leadership that is too distant from the issue may overlook problems, synergy options and trade-offs (Selnes et al., 2019).

The *Upper Rhine* case states that increasing coherence requires decompartmentalization of policy-making and implementation, a shift from a sectoral to a transversal logic. This is needed at different levels of legislation and at all levels of policy making, from research to implementation. This decompartmentalization represents both an organizational and sociological challenge. This governance innovation is supported by the *Sweden* case. Stakeholders in the case also advise to strengthen and develop transboundary cooperation on energy policy (Upper Rhine and Sweden SIM4NEXUS cases in Brouwer et al., 2020). The *Sardinia* case found a nexus approach relevant to promote a new paradigm and the importance of interactions among stakeholders of different sectors (Sardinia SIM4NEXUS case in Brouwer et al., 2020).
In *Azerbaijan,* cooperation across borders is relevant for a proper water resource planning since it is located downstream of its main river basins; 75% of the renewable water resources originate in neighbouring countries. Institutions in Azerbaijan welcome foreign help when domestic know-how is lacking or not sufficient. However, there are no or only very few initiatives that work cross-sectoral. Cross-sectoral cooperation could be an important factor for success of Azerbaijan's transition to a low-carbon economy (Azerbaijan SIM4NEXUS case in Brouwer et al., 2020).

The *Southwest UK* case advises cross-sectoral, cross-scalar and interconnecting governance. At the highest levels of policy decision making, more focus is needed across sectoral divides, to avoid fragmentation of the decision making and misinterpretation of policies by practitioners. Alongside more effective cross-departmental communication, there is a need for an appropriately placed cross-sectoral body to help understand, communicate and manage trade-offs and deal with the interactions of policies between nexus components. This will help to foresee future challenges and risks between sectors and implement policies that allow for optimal outcomes for the nexus rather than maximum outcomes for a single sector alone. The nexus-sensitive framings and principles set at a national level should be matched with local policy framings and responses. Working across scales will help to coordinate local visions and plans with national strategies, ensuring a more coherent approach to nexus issues. The creation of regional or local nexus hubs could help improve the dialogue between local and central stakeholders, help to translate national policy to local contexts and to mediate sticking points between multiple policy and regulatory actors. These centres could, for example, consolidate stakeholder links with local research communities such as universities (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).
The Netherlands case advised to stimulate area coalitions between farmers, provinces and other regional partners to establish or make use of synergy between water management, agriculture, sustainable production of renewable energy and nature development (Netherlands SIM4NEXUS case in Brouwer et al., 2020).

SIM4NEXUS recommendations:

- Strengthen and develop transboundary cooperation on water (drought and flooding, in addition to Water Framework Directive) and energy policy.
- Organise public-private partnerships to stimulate innovations.
- Enhance cross-sectoral approaches in foreign help, for example to Azerbaijan.
- Clearly define responsibilities for intersectoral and multiple-sector issues and policy-making in the WLEFC nexus.
- Seek for balance between leadership and overregulation.
- Set up cross-sectoral nexus bodies and regional and local nexus hubs to facilitate nexus approaches and the shift from a sectoral to a transversal logic in policy making.

5.2.4.3 Legitimacy

Legitimacy helps to gain support for the project. Recognised authority to implement change is important as empty promises quickly deplete trust. Building on already existing frameworks and establishments can help the project to gain legitimacy (Selnes et al., 2019).
Stakeholdersin the *Sweden* case noted the role of a small number of influential research groups and individuals in promoting political change. Therefore, they advised to cross the boundaries between academia, policy making and practice. They suggested to work with 'boundary organisations' to strengthen the science-policy interface, and influencers as part of the policy-making process (Sweden SIM4NEXUS case in Brouwer et al., 2020).

SIM4NEXUS recommendations:

- Use influencers to raise public awareness, for example about impacts of their consumption behaviour.

5.2.5 Resources, also for the 'in between' and 'total' of the nexus

A fair distribution of costs and benefits needs to be achieved, and equal opportunity to participate in the project for stakeholders. If the opportunity to participate for stakeholders in all sectors and the outcome of the project are considered fair, implementation of the project may be reached with higher acceptance. Clear implementation guidelines will avoid misunderstanding. and without measurable targets, monitoring is problematic. This becomes especially important when many sectors with different backgrounds and understandings are working towards a common goal. Access to the right resources, such as finances and a long-term management plan that allows for flexibility, is crucial for the successful completion of the policy initiative (Selnes et al., 2019).
The Southwest UK case advises to seek for balance between investment and benefits of a nexus approach. Benefits are, for example, policy coherence, and interdisciplinary learning and solutions (Southwest UK SIM4NEXUS case in Brouwer et al., 2020).

SIM4NEXUS recommendation:

- Agree upon financing the policy process and implementation of cross-sectoral and multi-sector policies.

5.2.6 Monitoring and evaluation, also synergies and trade-offs

Without measurable targets, monitoring is problematic. Monitoring is important for developing a shared understanding, building trust, adaptability of the project and enforcement. Monitoring the policy impact is fundamental for its success. Without monitoring, no progress can be measured. Monitoring is also important to provide information for future planning, to raise awareness, to assure trust among stakeholders is upheld and for the enforcement of the policy (Selnes et al., 2019). The *Latvia* case, for example, mentioned a lack of support for new measures in water management because of insufficient monitoring, related to lack of finances.

SIM4NEXUS recommendations:

- Learn from nexus monitoring and evaluation. Develop a database of implemented and evaluated nexus projects/policy and lessons learned, synergy and trade-offs.
- Assess cross-sectoral impacts of projects and policy and use this information as an eligibility or criterion for funding or implementation permission.
- Make databases of portfolios of European funding institutions such as the European Investment Bank more transparent, to facilitate investigations and evaluations of the WLEFC nexus compliance of investments.

Textbox 2

More transparency needed in portfolio database to investigate impacts on the WLEFC nexus of energy investments by the European Investment Bank

Investments in energy projects by the European Investment Bank (EIB) are not always coherent with European objectives for water, land, energy, food and climate (WLEFC). In 25 selected energy projects financed by the EIB, 25% of the 600 potential linkages of the projects with 24 selected European objectives resulted in conflicts with these objectives and 28% were synergetic. The other 43% were neutral or absent. The database of the EIB portfolio of energy investments is not sufficiently transparent to facilitate an overall evaluation of the compliance of these investments with European WLEFC objectives.

The EIB is one of the largest public investors in the European Union, and finances projects in the field of, for instance, energy, water, and infrastructure. A study investigated how the EIB considers the coherence of its investments in energy projects with European objectives for water, land, energy food and climate (WLEFC). This was explored in a systematic evaluation of EIB-financed energy projects that started between 2016 and 2020. The evaluation used the information in the Environmental Impact Assessments (EIAs) that are obliged for projects with expected environmental impacts.

The EIAs of only 139 out of the 333 energy projects that required an EIA were published in the project database of the EIB. Of those, only 20 were in English and 5 in another language that could be read by the researcher, limiting the scope of the evaluation. The coherence of these 25 energy projects with 24 European WLEFC objectives was analysed, leading to a total of 314 out of the potential 600 interactions.

A scoring method was used developed by Nilsson et al (2016). The scores ranged from -3 (Cancelling), meaning that implementation of the project has a permanent adverse effect on the achievement of a specific WLEFC objective, to +3 (Indivisible), meaning that the implementation of the project directly contributes to the achievement of a specific WLEFC objective. Of the 314 interactions, 47% was incoherent.

Incoherence can often be partly repaired by measures to mitigate and compensate for unavoidable negative impacts. After all, political choices have to be made between conflicting interests. This possibility however seems underused: very few EIAs with negative impacts contained information about mitigation and compensation measures.

Since EIB investments are initiated support European policy goals, 47% conflicting impacts can be considered as a high share. More transparency of the database would support more thorough and complete investigations of coherence of the investments with European goals (Mennen, 2020).

6 EU wide strategies and recommendations for coherent WLEFC policies

Recommendations, integrated policies, strategies and approaches are targeted at the ambitions and goals of the European Green Deal and its follow up programmes and actions.

6.1 Nexus compliant strategies to reach the goals of the European Green Deal

The European Green Deal sets five strategic goals towards 2050: 1. Economic growth and prosperity, 2. Reduction of greenhouse gas emissions to zero emission in 2050, 3. Resource efficiency, 4. Conservation and enhancement of EU's natural capital, 5. Protection of citizens from environment-related risks and impacts. The biggest nexus challenge is to develop strategies and pathways that can lead to reaching all these strategic goals together, as well as the uppermost sustainability goal 'Living well, within the limits of our planet', as there are many conflicts between these goals. SIM4NEXUS discovered three fundamental strategies.

6.1.1 'Upstream thinking'

According to model results for energy, food and water policies, most cost-effectivity and synergy within the WLEFC nexus can be reached if policies are prioritized according to the following order: 1. Change consumption behaviour to decrease demand for products, 2. Increase efficiency to reduce resource use and emissions 3. Meet potentially growing demand with renewable natural resources, investing in more sustainable production methods to reduce environmental impact of supply. SIM4NEXUS calls this 'Upstream thinking'. This strategy implies fundamental changes in human behaviour, economy and society. Many businesses and jobs within and outside Europe depend on unsustainable consumption and production within Europe, and people do not easily change behaviour and habits. There will be losers in this transition, but also new opportunities. There is a willingness to pay for more expensive solutions by those who can afford it, as long as they do not have to change their lifestyles and behaviour.
Changing consumption and behaviour to decrease the demand for products has the advantage of both decreasing greenhouse gas emissions and reducing resource use.

6.1.2 Maximize synergy between policies

Another strategy is seeking for synergy between measures as much as possible, especially between resource efficient and low-carbon pathways.

6.1.3 Protect and restore ecosystems and agricultural landscape

Protect and restore the quantity and quality of ecosystems and the services delivered by water, soil, land and landscapes, because these actions will create a cascade of synergies in the WLEFC nexus. Restore the degraded agricultural landscape. Nature-based solutions to prevent drought and floods and support climate change mitigation and adaptation are more synergistic with other European objectives in the WLEFC nexus than purely technical solutions.

6.2 Recommendations for WLEFC nexus compliant policies to serve the European Green Deal

6.2.1 Go beyond the sectoral perspective

Political will and mindset are necessary to broaden the scope beyond the usual sectoral perspective and put the long-term interest of a sustainable future above short-term profit. This also applies to the

implementation. Rules must be set and enforced, supported by necessary resources, and responsibilities must be clear, also for cross-sectoral issues.

Policies for different WLEFC nexus components could refer more to each other, and have a more systemic, cross-sectoral view, pointing out linkages, synergy and trade-offs between the policies and higher-level goals to be reached for the whole system.
Compare and share experiences with conflicting EU and national regulations, facilitate solutions to solve these conflicts and seek for opportunities offered by synergy between regulations. Spread out successful nexus implementations and scale them up in Europe.

6.2.2 Bring about fundamental changes

Developing a policy framework and policy instruments to stimulate a healthy and more plant-based diet for consumers at European scale is relevant, coherent and has added value, because 1. diet-related diseases are a widespread health problem, 2. production of animal-based food has huge environmental impact in and outside Europe, 3. a move to healthier and more plant-based diets is the most synergetic pathway to reach all goals for the WLEFC nexus, and several goals of the 'From Farm to Fork' strategy, 4. it is practical to have common standards and information about healthy food for all consumers, suppliers and producers in Europe. Effort must be put in educating people and investigating factors that make people keep or change their behaviour and consumption.
Trade-offs to livestock farmers and other businesses linked to animal-based food must be acknowledged and addressed to support the transition.

Investigate if similar policies should be developed at national and European scales, targeted at changing consumer behaviour to reduce energy demand, without increasing energy poverty, and reduce water demand and water footprints. This strategy could reduce the demand for other resources as well.

6.2.3 LCA for coherence between resource efficient and low-carbon pathways

Use Life Cycle Analyses for both low-carbon and resource efficient pathways to avoid trade-offs between the two. Capture synergy between both pathways.

6.2.4 Improve data access and database interoperability between policy areas

Install a policy that regulates data access and database interoperability to coordinate cross-sectoral data exchange, both horizontally and vertically. A framework directive at European scale could support this action and support cross-border data exchange.

6.2.5 Make REDII more WLEFC nexus compliant

The Renewable Energy Directive (RED) and the Common Agricultural Policy (CAP) cause the most trade-offs in the WLEFC nexus. Policies for water and soil, as well as stimulating resource efficiency in the agriculture, food and forestry sectors, create most synergies.

SIM4NEXUS results lead to the following recommendations for the revision of REDII:

- The cross-compliance and greening conditions in the CAP could also count for energy generated from crops that Member States can count towards their national targets when calculating the national share of renewables.
- Sustainability criteria for biobased energy resources from Europe as well as abroad, should become more transparent, verifiable, and strict. Sustainability criteria for biodigesters must be specified.

- Policies that stimulate the use of renewable energy, especially bioenergy, should only be put in place, if potential negative effects on environment and food security, as well as climate neutrality are assessed and avoided or mitigated.
- The effects of increasing the use of bioenergy on food security and food prices should be better addressed. It must be clear how the European Commission will monitor these effects and what concrete actions will be taken if unwanted effects are observed.
- Do not stimulate the installation of scattered small-scale biomass energy plants.
- Impacts from renewable energy generation on water quantity and quality, as well as impacts on hydrological cycles, must be better addressed and more strictly regulated. This cannot be left to voluntary schemes. Also, the dependency of renewable energy generation on water availability and negative effects of competition for water in case of scarcity, should be assessed and addressed in the context of climate change.
- Trade-offs of large-scale monoculture in agriculture to the landscape and soil, hydrological cycle, local climate and adaptation capacity, should be addressed in the REDII (bioenergy crops) as well as the CAP.
- The use of biobased natural resources for energy generation must be weighed against higher value use in the biobased economy, as sustainably produced biobased resources will probably become scarce.

Other recommendations for renewable energy, made by SIM4NEXUS cases are:

- Stricter regulation for land take and environmental impacts by bio-energy crops and solar farms (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020). This goes well with the Farm to Fork strategy to place solar panels on farmhouses and barns and prioritise such investments in the future CAP Strategic Plans. In general, address competing claims on land and water for food, feed, fibre and bioenergy crops.
- Stimulate innovation in bioenergy generation, sources, use and efficiency (Southwest UK and Latvia SIM4NEXUS cases in Brouwer et al., 2020).
- Strengthen and develop transboundary cooperation on energy policy (Upper Rhine SIM4NEXUS case in Brouwer et al., 2020).

6.2.6 Make the CAP more WLEFC nexus compliant

The CAP revision offers the opportunity to mainstream WLEFC nexus thinking, as it is relevant for all nexus sectors (agricultural food production, bioenergy production, biodiversity conservation, adaptation to climate change and improving climate resilience, climate change mitigation, as well as water management).

Recommendations stemming from SIM4NEXUS results are:

- Support farmers in the transition from livestock to horticulture and arable farming, and stimulate the growth of crops that deliver plant-based proteins.
- Stimulate new, innovative business models for sustainable farming combined with deliverance of ecosystem service and public services, to increase and secure farm incomes.
- Support farmers to adapt to climate change.
- Take local and regional climate change caused by degradation of the agricultural landscape and disturbance of the hydrological cycle seriously, and investigate occurrence and extent within Europe.
- Stimulate the restoration of the landscape and hydrological cycles, and soil-conserving agriculture. Include the restoration of the agricultural landscape and hydrological cycles in the CAP strategic plans by the Member States, where appropriate. Include good management practices of soil and water in the CAP. All this can very well go together with multifunctional agriculture, organic farming, production of local food, payment for delivering ecosystem

services, increasing natural areas and forests. These measures also serve the long-term continuation of high productive farming.

- Support multifunctional agriculture that produces food and energy, supports biodiversity and climate resilience.
- Bridge the controversy between economic and ecologic interests in agriculture and the CAP, by developing new narratives about the short-term and long-term shared interests and profits.
- Include cross-compliance with the Water Framework Directive in the CAP, as suggested in the current proposals. Cross compliance with water quantity targets, for example keeping minimal ecological flows, could also be included.
- Stimulate nature-based solutions to solve water and soil problems in agricultural rural areas.
- The proposal for the CAP revision to set stricter greening conditions for payments is supported, as well as better implementation and enforcement in the Member States, for example the standards for GEAC.
- Stimulate the growth of less water-demanding and climate change resilient crops. Increase diversification of crops.
- Put a maximum on irrigated area and water withdrawal, as one of the conditions for financial support in the Mediterranean.
- Stimulate efficient irrigation systems that do not need extra energy to function, stimulate sensor-based irrigation to reduce water demand and fertilization requirements.
- Use the CAP strategic plans and eco-schemes financing options to support the growth of forests.
- Be prudent with stimulating biodigesters on farms, as there may be many negative impacts.
- Reduce the administrative burden of financing schemes.
- Use the CAP to create synergy between water management, agriculture, sustainable production of energy and nature protection and development.
- Base CAP financing on delivered services instead of hectares and production.

Other recommendations for agricultural practices, made by SIM4NEXUS cases are:

- Focus on the synergies between nature and agriculture and stimulate nature inclusive agriculture.
- Sweden and comparable countries and regions with a sustainable image, could better promote and utilize its image of environmentally friendly food producer and build its market competitiveness on it.

6.2.7 Better coordinate land and water management

- Better define and regulate Minimum Environmental Flows (MEF), to have a legal tool for limiting the withdrawal of surface water by actors in the drainage basin, and protect water quantity and quality of rivers and streams.
- Better integrate land use and soil management with water management in the drainage basin.

6.3 Recommendations for WLEFC nexus compliant policy governance

These recommendations are mainly based on the SIM4NEXUS case study findings in chapters 3 to 5, and where they were complimentary, on the structured literature review in the Annex.

6.3.1 Fair and inclusive policy process of paramount importance

Only with broad ownership and commitment, the ambitious goals of the European Green Deal can be reached. It is recommended to invest in a multidisciplinary participative process during the whole

policy cycle. Coherent, balanced, inclusive and fair nexus pathways to reach the goals of the European Green Deal will only be possible in a process with equal power relations between the sectors involved. Potential shared benefits and common interests between sectors must be investigated and communicated in messages that resonate with the audience. Asymmetries in power allow actors to exploit nexus resources in line with their own goals, disregarding negative impacts elsewhere or to the detriment of goals of other, powerless, actors. Obstacles and objections stemming from conflicting interests and viewpoints must be assessed and addressed.

6.3.2 Work in integrating themes

Integrating themes stimulate a nexus approach. Institutionalize these nexus themes between policy fields and scales to create transversal instead of sectoral views, balancing between flexibility and long enough time to create cross-sectoral expertise and understanding of different viewpoints. Promote communication and interaction between siloed policy fields and encourage them to see each other's perspective.

6.3.3 Recommendations to implement nexus success factors

6.3.3.1 Experiment with nexus governance success factors

An extensive list of success factors for nexus policy governance was composed (Table 5 in section 5.1). By applying the success factors in practice, it must be explored which success factors work in which situations to make nexus governance 'good enough'.

6.3.3.2 Cross-sectoral and cross-scale knowledge management and relational learning important during whole policy process

SIM4NEXUS recommendations:

- Organise mutually exchange of knowledge and insights between and within the science and policy processes during the whole policy cycle.
- Assign an important role to social sciences in the scientific process, and ensure better understanding of consumer behaviour.
- Meetings between stakeholders with opposite viewpoints that adhere to different discourses must be facilitated repeatedly, to create and keep understanding for different interpretations and framings in a context of contested science.
- Facilitate the exchange of knowledge and insights with tools such as serious games, tailor-made, clarifying and attractively visualised information, and process supporting tools such as Joint Fact Finding.
- Make nexus and cross-sectoral coherence assessments part of inception impact assessments to define the nexus scope of the policy-making process and decide about disciplines and stakeholders to be involved. Check and adjust the scope during the policy process, because of advancing insights and new phases in the process.
- Develop a framework, including definitions, to make data between policy fields and scales mutually comparable. Make data open access and easy to use. Develop a database of quantified nexus linkages.
- Involve stakeholders in the development of scenarios and assumptions underlying models, as well as in social-science research design.
- Besides top-down, also use bottom-up approaches to create local awareness, increase acceptance especially if measures concern habits and routines, learn about local needs and gather local knowledge.
- Strive for integrative governance, i.e. the use of ICT to transform government by making it more accessible, effective, and accountable to its citizenry (World Bank).

6.3.3.3 Deal with uncertainty and complexity, also cross-sectoral

SIM4NEXUS recommendations:

- Plan for adaptability and allow for objectives and targets to be revised to keep them relevant. Acknowledge this already in the planning phase to prepare stakeholders and players that changes may happen along the way.

6.3.3.4 Permanently work on shared visions

SIM4NEXUS recommendations:

- Share and check viewpoints repeatedly, as visioning is a continuous process.
- Start educating children early in school programmes to raise awareness, enable transdisciplinary and cross-sectoral cooperation and 'eliminate' silo-thinking, for example by letting pupils and students work on interdisciplinary themes.
- Organise discussions about the societal effects of the low-carbon and resource efficiency transitions, and about land-use change caused by the increase in renewable energy and decrease of consumption of animal-based food.

6.3.3.5 Work on cross-sectoral and cross-scale cooperation with fair and equal power relations

SIM4NEXUS recommendations:

- Strengthen and develop transboundary cooperation on water (drought and flooding, in addition to Water Framework Directive) and energy policy.
- Organise public-private partnerships to stimulate innovations.
- Enhance cross-sectoral approaches in foreign help, for example to Azerbaijan.
- Clearly define responsibilities for intersectoral and multiple-sector issues, policy making and implementation in the WLEFC nexus, also cross-scale.
- Seek for balance between leadership and overregulation.
- Set up cross-sectoral nexus bodies and regional and local nexus hubs to facilitate nexus approaches and the shift from a sectoral to a transversal logic in policy making. On the other hand, be pragmatic and broaden mandates of sectoral policymakers only to the extent possible.

6.3.3.6 Work on legitimacy and support

SIM4NEXUS recommendation:

- Use influencers to raise public awareness, for example about impacts of their consumption behaviour.
- Introduce a more appealing framing of the nexus in a unifying, common way, for instance through security, the SDGs or sustainable innovation.
- Formulate messages that resonate with the different audiences.

6.3.3.7 Finance the 'in between' and 'total'

SIM4NEXUS recommendation:

- Agree upon financing the policy process and implementation of cross-sectoral and multi-sector policies.

6.3.3.8 Nexus-oriented monitoring and evaluation

SIM4NEXUS recommendations:

- Learn from nexus monitoring and evaluation. Develop a database of implemented and evaluated nexus projects/policies and lessons learned, cross-sectoral synergy and trade-offs.
- Assess cross-sectoral impacts of projects and policies and use this information as an eligibility or criterion for funding or implementation permission.
- Make databases of portfolios of European funding institutions such as the European Investment Bank more transparent, to facilitate investigations and evaluations of the WLEFC nexus compliance of investments.

6.4 Bringing nexus approach into practice is a challenge

The added value of a nexus approach is that options for synergy are used, unforeseen and unwanted trade-offs avoided, more transparency created, and innovative solutions developed because of interdisciplinary cooperation.
A nexus approach is still more theory than practice, but viewpoints and framings seem to change from sectoral approaches to thematic and system approaches, even if the word 'nexus' is not mentioned, for example in the European Green Deal, From Farm to Fork strategy, and in Horizon Europe (Selnes, 2020b). However, these too are still strategies that need to be worked out and implemented.
Comparably, there is full awareness of nexus relations in the implementation process of the Sustainable Development Goals, but it seems hard to realize a nexus approach for implementation, monitoring and evaluation. Examples of cases that followed a nexus approach, finished, were evaluated and judged successful, are rare.
Multiple definitions of a nexus approach exist, and many different combinations of nexus components. THE nexus does not exist, it is an approach, mindset, lens to look at problems and solutions. In theory, in a nexus approach all nexus components are equally important and equally addressed, and the nexus is seen as a higher-level system. In practice, problems are tackled starting from one nexus component and one sector, and at best, relevant other components and interests are considered from that viewpoint. Equal importance of different sectors, and equal power relations, are not reality.
Theory still needs to be brought into practice. European, national or regional policies are not monitored and evaluated from a nexus perspective, so there is no information if they were successful in that sense, and there is not yet a learning process.
In a nexus approach, a problem should be considered from multiple viewpoints, and multiple interests and goals to find an optimum for the whole nexus system. This is not just a scientific process as a pure technical optimum principally does not exist, and goals are defined for separate components of a nexus. It takes political decisions about priorities to define an optimum state of the whole nexus.

6.4.1 Suggestions for further research

(See Annex for references).

A lack of knowledge of nexus interactions and gaps in nexus science can partially be solved by extra research and data gathering. A lack of data on interlinkages of the nexus is mentioned by many studies (D'Odorico et al., 2018; Johnson et al., 2019; Larsen et al., 2019; J. Liu et al., 2017; Markusson et al., 2012; Said et al., 2019). Empirical evidence of a successful nexus approach, along with practical evaluations of the implementation and contextual factors, would be of value. Reviews find it difficult to validate claims that the nexus approach has improved resource management or governance outcomes (Galaitsi et al., 2018). (Hoff et al., 2019) attempts to break the vicious cycle of presenting several case studies without the ability to draw generalisable conclusions.
In addition to these points, several authors make recommendations on the conduct and the type of research. Several highlight that multi- and transdisciplinary research is necessary (Albrecht et al., 2018), and that stakeholders should be involved in the design of the research.

7 References

- Alliance Environment (2019). Evaluation of the impact of the CAP on habitats, landscapes, biodiversity. European Commission Directorate-General for Agriculture and Rural Development. https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/ext-eval-biodiversity-final-report_2020_en.pdf
- Blanco, M. et al. (2020). D3.5: Final report on the application of thematic models. Horizon2020 SIM4NEXUS. https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable_D3.5%20update.pdf
- Brouwer, F., M. Fourier et al (2020). D5.5: Outcome of task 5.2 Supporting decision making in 12 case studies. Horizon2020 SIM4NEXUS.
- Cambridge Econometrics (2019). E3ME Technical Manual v6.1. Cambridge, UK. https://www.e3me.com/wp-content/uploads/2019/09/E3ME-Technical-Manual-v6.1-onlineSML.pdf
- Commission on Global Governance (1995). Our Global Neighborhood. Oxford: Oxford University Press.
- Eklund A. et al. 2015. Sveriges framtida klimat - underlag till dricksvattenutredningen (en: 'Sweden's climate - a basis for investigating drinking water), Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden. http://www.smhi.se/polopoly_fs/1.96078!/Menu/general/extGroup/attachmentColHold/mainCol1/file/klimatologi_14.pdf
- Doelman, J. C., E. Stehfest, A. Tabeau, & H. van Meijl (2019). Making the Paris agreement climate targets consistent with food security objectives. *Global Food Security,* 23, 93-103.
- European Commission, 2001. *European Governance: A White Paper*. [COM(2001)] Brussels. http://europa.eu/rapid/press-release_DOC-01-10_en.htm [Accessed 23 Mar. 2018].
- European Commission (2011). Roadmap to a Resource Efficient Europe. COM(2011) 571
- European Commission (2012a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the Committee of the Regions. A Blueprint to Safeguard Europe's Water Resources. COM(2012) 673 final. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0673&from=EN
- European Commission (2012b). Guidelines on best practice to limit, mitigate or compensate soil sealing. Publications Office of the European Union, Luxembourg. https://ec.europa.eu/environment/soil/pdf/guidelines/pub/soil_en.pdf
- European Commission (2013) Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the Committee of the Regions. A new EU Forest Strategy: for forests and the forest-based sector. COM(2013) 659 final. https://eur-lex.europa.eu/resource.html?uri=cellar:21b27c38-21fb-11e3-8d1c-01aa75ed71a1.0022.01/DOC_1&format=PDF.
- European Commission (2014). General Union Environment Action Programme to 2020. Living well, within the limits of our planet. Publication Office of the European Union, Luxemburg. https://op.europa.eu/en/publication-detail/-/publication/1d861dfb-ae0c-4638-83ab-69b234bde376/language-en/format-PDF.
- European Commission (2017a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Region. An Action Plan for nature, people and the economy {SWD(2017) 139 final}. COM(2017) 198 final. https://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/communication_en.pdf
- European Commission (2017b). Commission staff working document. Factsheets providing details of actions in the Action Plan for nature, people and the economy. Accompanying the

document Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions An Action Plan for nature, people and the economy {COM(2017) 198 final}. SWD(2017) 139 final. file:///C:/Users/Maria%20Witmer/Documents/SIM4NEXUS/EU%20policies/EC_2017_Action%20plan%20nature,%20people%20and%20economy.pdf

- European Commission (2019a). The European Green Deal. COM(2019) 640 final. https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf
- European Commission (2019b). Annex to the European Green Deal. COM(2019) 640 final. https://ec.europa.eu/info/sites/info/files/european-green-deal-communication-annex-roadmap_en.pdf.
- European Commission (2019c). Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the status of production expansion of relevant food and feed crops worldwide. COM(2019) 142 final. https://eur-lex.europa.eu/resource.html?uri=cellar:b160eb62-4580-11e9-a8ed-01aa75ed71a1.0008.02/DOC_1&format=PDF
- European Commission (2019d). Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC). Second River Basin Management Plans. First Flood Risk Management Plans. COM(2019) 95 final. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=COM:2019:95:FIN&from=EN
- European Commission (2019e). The post-2020 Common Agricultural Policy: Environmental benefits and simplification. https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-post-2020-environ-benefits-simplification_en.pdf
- European Commission (2019f). Report of the Work of the Task Force on Mobilising Efforts to Reach the EU Energy Efficiency Targets for 2020. Directorate General for Energy, Brussels, Directorate C. https://ec.europa.eu/energy/sites/ener/files/report_of_the_work_of_task_force_mobilising_efforts_to_reach_eu_ee_targets_for_2020.pdf
- European Commission (2020a). A new Circular Economy Action Plan For a cleaner and more competitive Europe. COM(2020) 98 final. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF
- European Commission (2020b). Annex to a new Circular Economy Action Plan For a cleaner and more competitive Europe. COM(2020) 98 final. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_2&format=PDF
- European Commission DG CLIMA (2020c). Inception Impact Assessment of 2030 Climate Target Plan. Ref. Ares(2020)1631599 - 18/03/2020.
- European Commission (2020d). Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). COM(2020) 80 final. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020PC0080&from=EN
- European Commission (2020e). Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the Committee of the Regions. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM(2020) 381 final. https://eur-lex.europa.eu/resource.html?uri=cellar:ea0f9f73-9ab2-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF
- European Commission (2020f). Better regulation toolbox. Tool #47. Evaluation criteria and questions. https://ec.europa.eu/info/sites/info/files/file_import/better-regulation-toolbox-47_en_0.pdf. Consulted on 20200714.

- European Commission (2020g). Commission staff working document. Analysis of links between CAP Reform and Green Deal. SWD(2020) 93 final. https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/sustainability_and_natural_resources/documents/analysis-of-links-between-cap-and-green-deal_en.pdf
- European Commission (2020h). Review of the Directive 2012/27/EU on Energy efficiency. Combined evaluation roadmap/Inception impact assessment. DG ENER Unit C3. Ref. Ares(2020)4101900 – 04/08/2020. file:///C:/Users/Maria%20Witmer/Downloads/090166e5d2424c4b%20(1).pdf
- European Commission (2020i). Revision of Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. Inception Impact Assessment. DG ENER Unit C1. Ref. Ares(2020)4087053 – 03/08/2020. file:///C:/Users/Maria%20Witmer/Downloads/090166e5d239f073%20(1).pdf
- European Environmental Agency (2019). The European environment - state and outlook 2020. Knowledge for transition to a sustainable Europe.
- European Union (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 october 2000 establishing a Framework for community action in the field of water policy. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02000L0060-20141120&from=EN.
- European Union (2018a). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast). https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN
- European Union (2018b). Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2002&from=EN
- European Union (2018c). Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0841&from=EN
- Frank, Stefan, Hannes Böttcher, Petr Havlík, Hugo Valin, Aline Mosnier, Michael Obersteiner, Erwin Schmid, and Berien Elbersen (2013). How effective are the sustainability criteria accompanying the European Union 2020 biofuel targets? *GCB Bioenergy* 5 (3): 306–14. https://doi.org/10.1111/j.1757-1707.2012.01188.x.
- Hasegawa Tomoko, Shinichiro Fujimori, Petr Havlik, Hugo Valin, Benjamin Bodirsky, Jonathan Doelman, Thomas Fellmann, Page Kyle, Jason F.L. Koopman, Hermann Lotze-Campen, Daniel Mason-D'Croz, Yuki Ochi, Ignacio Perez-Dominguez, Elke Stehfest, Timothy B. Sulser, Andrzej Tabeau, Kiyoshi Takahashi, Jun'ya Takakura, Hans van Meijl, Willem-Jan van Zeist, Keith D. Wiebe, Peter Witzke (2018). Risk of increased food insecurity under stringent global climate change mitigation policy, Nature Climate Change, volume 8, pages 699–703
- Helmisaari H.-S. et al (2014). Increased utilization of different tree parts for energy purposes in the Nordic countries, Scand J Forest Res, 29(4), 312–322, doi:10.1080/02827581.2014.926097.
- IPCC (2014). Climate Change 2013: The Physical Science Basis, edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, J. Xia, V. Bex, and P. M. Midgley, Cambridge University Press, Cambridge, UK, and New York, USA.
- Jacob D. et al (2014.) EURO-CORDEX: new high-resolution climate change projections for European impact research, Reg Environ Change, 14(2), 563–578, doi:10.1007/s10113-013-0499-2.

- Van Meijl Hans, Petr Havlik, Hermann Lotze-Campen, Elke Stehfest, Peter Witzke, Ignacio Pérez Domínguez, Benjamin Bodirsky, Michiel van Dijk, Jonathan Doelman, Thomas Fellmann, Florian Humpenoeder, Jason F.L. Koopman, Christoph Mueller, Alexander Popp, Andrzej Tabeau, Hugo Valin, Willem-Jan van Zeist (2018). Comparing impacts of climate change and mitigation on global agriculture by 2050, Environ. Res. Lett. 13 064021. https://doi.org/10.1088/1748-9326/aabdc4.
- Mennen, Corné, 2020. Coherence between European investments in the energy sector and the WLEFC-NEXUS. Radboud University Master Thesis. Available on: https://www.sim4nexus.eu/userfiles/MASTERTHESIS_WLEFC_NEXUS_def.pdf
- Munaretto, S., MCH Witmer et al (2017). D2.1 Water-land-energy-food-climate nexus: Policies and policy coherence at European and international scale. Horizon2020 SIM4NEXUS. https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable_D2.1%20resubmission%20after%20review%20with%20annex%201.pdf
- Munaretto et al (2019). SIM4NEXUS D2.2 Nexus-relevant policies in the transboundary, national and regional case studies. Main Report. Horizon2020 SIM4NEXUS. https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable%202.2_Policy%20analysis%20case%20studies_final-report_2019.02.18.pdf
- The Nature Conservancy (assessed 1 August 2020). http://naturalclimatesolutions.org/.
- Newell, J. P., B. Goldstein and A. Foster2 (2019). A 40-year review of food–energy–water nexus literature and its application to the urban scale. https://iopscience.iop.org/article/10.1088/1748-9326/ab0767/pdf
- Niestroy, I. and Meuleman, L (2016). Teaching Silos to Dance: A Condition to Implement the SDGs. http://sdg.iisd.org/commentary/guest-articles/teaching-silos-to-dance-a-condition-to-implement-the-sdgs/
- Nilsson M., T. Zamparutti, J.E. Petersen, B. Nykvist, P. Rudberg, J. McGuinn (2012). Understanding policy coherence: analytical framework and examples of sector-environment policy interactions in the EU. *Environmental Policy and Governance* 22: 395-423.
- Nilsson, M., Griggs, D., & Visbeck, M (2016). Policy: Map the interactions between Sustainable Development Goals. *Nature*, *534*(7607), 320–322. https://doi.org/10.1038/534320a
- O'Neill B.C., Kriegler E., Ebi K.L., Kemp-Benedict E., Riahi K., Rothman D.S., van Ruijven B.J., Van Vuuren D.P., et al (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42, 169–180.
- Ramos, E. et al (2020). D1.5: Framework for the assessment of the nexus. Horizon 2020 SIM4NEXUS.
- Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'neill, B. C., et al. (2017). The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global Environmental Change, 42, 153-168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
- Roots E.F (1989). Climate change: High-latitude regions, Climatic Change, 15(1), 223–253, doi:10.1007/BF00138853.
- Rytter L. et al (2013). Tree Species, Genetics and Regeneration for Bioenergy Feedstock in Northern Europe, in Forest BioEnergy Production: Management, Carbon Sequestration and Adaptation, edited by S. Kellomäki, A. Kilpeläinen, and A. Alam, pp. 7–37, Springer Science + Business Media, New York, USA. [online] Available from: http://dx.doi.org/10.1007/978-1-4614-8391-5_2
- Sandström C. et al (2011). Governing Competing Demands for Forest Resources in Sweden. Forests, 2(4), 218–242, doi:10.3390/f2010218.
- Selnes, T., R. Oakes, MCH Witmer et al (2019). Nexus policy improvements. Deliverable 2.4: Executive summary of nexus relevant policies and recommendations for policy improvements. Horizon2020 SIM4NEXUS. https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable_D2.4.pdf

- Selnes, T (2020a). Summarising the policy recommendations from all case studies. SIM4NEXUS Deliverable 5.6. https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable_D5.6.pdf.
- Selnes, T (2020b). D5.10 Outcome of the EU-workshop. Horizon 2020 SIM4NEXUS.
- Stenmarck, Å et al (2016). Estimates of European food waste levels. FUSIONS. ISBN 978-91-88319-01-2. https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf
- Svensson, S., (2018). Governance of the Water-Land-Energy-Food-Climate Nexus: an investigation for the conditions of success. Master thesis Vrije Universiteit.
- UNFCCC, United Nations Framework Convention on Climate Change (2015). Adoption of the Paris Agreement. Conference of the Parties 24th session, Paris, 12 December 2015.
- UNEP (2012) Healthy waters for sustainable development. UNEP operational strategy for fresh water (2012-2016). UNON Publishing Services Section, Nairobi, Kenia.
- UN General Assembly (2015). Transforming our world: the 2030 Agenda for Sustainable Development.
- Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., et al. (2011). The representative concentration pathways: an overview. Climatic Change, 109(1-2), 5-31. https://doi:10.1007/s10584-011-0148-z.
- Vink, M. and A. Hinsberg (2019). Stikstof in perspectief. Planbureau voor de Leefomgeving (PBL), The Hague, The Netherlands (In Dutch). https://www.pbl.nl/publicaties/stikstof-in-perspectief.
- Willett, W., Rockström, J. et al (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*.
- Witmer, M.C.H., R. Oakes, S. Svensson et al (2018). D2.3: Policy success stories in the water-land-energy-food-climate nexus. Horizon2020 SIM4NEXUS. https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable_D2.3%20resubmission.pdf
- World Energy Council (2019). Energy Trilemma Index. https://www.worldenergy.org/publications/entry/world-energy-trilemma-index-2019
- Woltjer G., M. Kuiper et al (2014). The MAGNET Model: Module description. LEI Wageningen UR, Wageningen. https://edepot.wur.nl/310764

8 Annex: Lessons from a structured literature review

Authors: Floris Swennenhuis and Heleen de Coninck, Radboud University

8.1 Introduction

The SIM4NEXUS case studies have highlighted both the value and the difficulty of the nexus approach. They also show the variety of nexus approaches, and that the policy response differs greatly depending on the context. When adopting a nexus approach, a policymaker would ideally consider and address all nexus components on an equal footing, while accounting for potential synergies and trade-offs that occur through interactions between the nexus components. In practice, however, such an ideal nexus situation is never achieved, as demonstrated by a wealth of literature as well as by the SIM4NEXUS case studies. While the modelling studies that point out the promise of the nexus tend to optimise, case studies demonstrate that, in reality, policymakers and other stakeholders at most satisfice (Grubb et al, 2014).

Why is it impossible to optimise? In practice, the starting point of solving a policy problem tends to be one nexus component, generally in one sector. Relevant other components and interests are then considered, but the starting point theme or sector remains dominant in the policy response. Still, even when a nexus-optimisation approach is only possible in computer models, a wide spectrum exists in the extent to which different cases of policy problems in the literature manage to take into account other nexus elements beyond the starting point, and successfully arrive at synergies in combined policy aims.

The question addressed in this chapter is: what can be learned from nexus case studies in the broader literature? Through these lessons, the added value of a nexus approach is further unpacked, and the conditions under which this added value can be achieved are clarified. The aim is to identify empirically based, practical policy recommendations focussed on the process needs for addressing the nexus.

Much of the nexus-related literature consists of case study assessments that look for physical linkages between nexus components. Such studies invariably find that the nexus should be taken into account by decision-makers, or one or more components will suffer negative impacts. This is bad in itself, but also undermines support for the original policy aim. Many case studies arrive at recommendations on what decision-makers need to change for a more integrated nexus-view. These recommendations are highly dependent on the context, complicating generalizable and practical advice. Through a structure literature review, this chapter aims to find what general recommendations can be made on the process of nexus policy.

The next section introduces how the structured literature review was done, section 6.3 characterises the papers found, section 6.4 discusses the key results and conclusions, and section 6.5 identifies the practical policy recommendations on the nexus policy process needs.

8.2 Methodology

A structured literature review was conducted to identify the lessons from case studies. To arrive at a set of case study publications and meta-analyses, first a search in Web of Science was conducted, including references in the publications found in the first results. This was done to also include non-peer reviewed literature sources, such as reports by research institutes and think tanks.

The searches were performed based on sets of keywords that included either: nexus / integrated and a combination of water / land / energy / food / climate / natural resource(s). Considering the overall goal of developing policy recommendations, inclusions of additional keywords were attempted, such as management, governance, policy and implementation, as well as the exclusion of modelling, but this did not significantly change the results of the literature search.
Papers were selected through a first and second pass based on reading the title and abstract. This resulted in a set of 84 papers and reports. Selected literature was examined in more detail, and the paper's results were evaluated on the elements in Table 6.

Table 6. Overview of elements of the structured nexus literature review

Type of study • Theory • Empirical **Publication type** • Journal paper • Report • Other **Approach** • Modelling • Case study • Assessment • Meta-study • Ex-ante • Ex-post	**Nexus elements** • Water • Land • Food • Energy • Climate **Starting point** • Nexus element • Other sector (e.g. city, waste)	**Scale** • Global • Regional • National • Local **Geography** • EU • Non-EU	**Conclusions on:** • Enablers & opportunities • Barriers • Conditions and context

The elements evaluated in the structured literature review, and the rationale for including them, is as follows:

- Type of study and publication type: We evaluated some key core characteristics of the study: whether it primarily takes a theoretical or an empirical approach (or both; where synthesis studies are reported as theoretical even when based on empirical work) and whether the publication is a journal paper (having undergone peer review) or a research report.
- Approach: We distinguished between ex-post and ex-ante evaluations, and between modelling, assessment, case study and meta-study/review-based approaches. Besides key information for the structured review, these categorisations can help identify a potential lack of evidence or other gaps in nexus-related research.
- Nexus elements and starting point: We noted which of the WLEFC elements are explicitly part of the nexus for each paper, as well as the starting point or perspective for each study, for example, a study can look at the nexus from an agricultural or water infrastructure perspective, or from a completely different perspective, like urban questions, or waste reduction.
- Geography and governance level: The geography (EU and non-EU) and governance level at which the studies operated was identified. The governance level is relevant at both the physical level (water sources, for example, often cross national borders, and the use of water in one region directly affects other regions) and for regulation and policy (transboundary agreements in river basins, to stay with the same example). Global, regional, national and local governance levels are distinguished, but this does not imply a hierarchy: although a

region can be much larger than a country, a national government may supersede the regional administration.

The categorisations are not mutually exclusive. For example, a paper can discuss both an ex-ante and ex-post situation, it can develop an assessment method and apply it to a case study, and a meta-study can evaluate the nexus in both EU and non-EU regions. In these cases, papers are marked as having all relevant attributes. Hence, summing studies of these attributes may exceed the total number of studies. In some cases, papers might not fit any of the categories, therefore, the sum may be less than the total number of studies. For this, iteratively new categories were added as the review unfolded, but some 'others' remained. Because of these factors, and because we don't think our assessment is exhaustive, specific quantitative analysis of the results would be meaningless and is hence not attempted.

The key conclusions of studies are summarised in the categories a) barriers, b) enablers and opportunities, and c) context and conditions. These will be synthesised to construct the lessons learned of how to increase the likelihood that potential synergies take place, and that trade-offs are avoided or compensated, while recognising that optimisation in a nexus approach situation is generally not possible.

8.3 Overview of the cited studies

8.3.1 Type of study and approach

The amount of studies on the nexus has increased significantly since the first mention during the World Economic Forum of 2011 (Bazilian et al., 2011) (see Figure 8). The vast majority of the studies assessed were journal papers; only the occasional report or book was reviewed. In our search, about twice as many empirical studies as theoretical studies were identified. A number of studies, but less than ten, combined theoretical and empirical approaches. The theoretical studies used a mix of methods; about half of them employed modelling, many jointly with other methods, in particular assessment and meta-study, but also sometimes case study. However, just as many used a mix of approaches. Theoretical studies often could not be allocated to an ex-ante or ex-post category, though of the studies for which this could be determined, slightly more undertook an ex-ante analysis of the nexus measures.

Case study is the predominant approach in the more empirically-focussed studies; almost all had case study elements. Many of the empirical case study publications could not be allocated in the ex-ante or ex-post categories, but surprisingly, most of the studies that could, were classified as ex-ante. Those that are neither ex-ante or ex-post constituted the majority, and for instance are studies that try to make model-based projections for a particular case based on partially historical data (Guan et al., 2020).

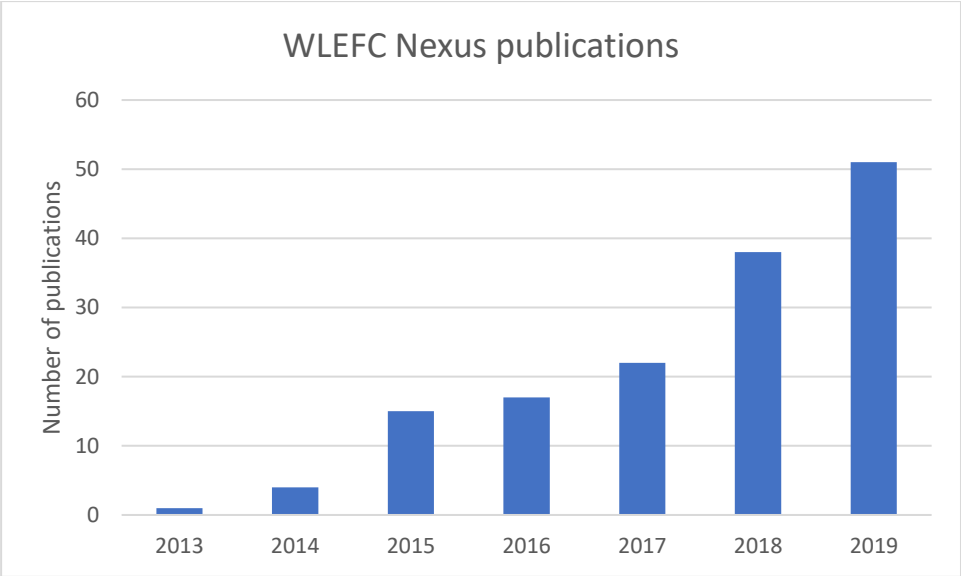

Figure 8. The amount of WLEFC nexus publications by year in peer-reviewed journal and conference publications. Search results on Web of Science for search terms 'nexus water land energy food climate' between 2010 and 2019

8.3.2 Nexus elements and starting point

The vast majority of recent Nexus literature explicitly mentions water (78), energy (74) and food (68) as elements of the nexus in either the title, key words or abstract. Land (17) or climate (11) were less mentioned explicitly, but given their interlinkages with food and water, and energy, respectively, it was sometimes difficult to demarcate the line between those elements. The WEF nexus is mainly interlinked with land through agriculture and ground water. For example, a paper by (Zheng et al., 2019) explores the 'WEF' nexus from a an agricultural perspective, (Talozi et al., 2015) investigates the impact of virtual water on 'WEF' nexus policy and a publication by (Simpson et al., 2019) analyses competition for land in the 'WEF' nexus and coal mining.

This is in contrast to how SIM4NEXUS handles the distinction between food and land. Food is considered a socioeconomic domain containing food production through agriculture, processing of agricultural products and food consumption, as well as the supply chains associated with those. Land is defined as the land and soil system, or a geographical phenomenon. It is a natural resource characterised by the extent and intensity of use.

In most papers, climate is more clearly distinguished from the other elements. Climate is often approached as external to the system that is the core scope of the study, which is often also the system that can be influenced by actors, or modelled within the scope of the paper. For example, climate change is seen as a threat to WEF resources in in Tanzania (Said et al., 2019), or as a driver for decarbonisation of the Spanish electricity sector, and its effects on the WEL nexus (Lechón et al., 2018).

Climate change, or sometimes GHG emissions specifically, are also placed on the other side of the system, as an output of the nexus, i.e. emissions as the result of functions in water, energy and food. This is common as the WEF-nexus is a much more often used nexus than the WLEFC-nexus that SIM4NEXUS has chosen. For instance, (Fan et al., 2020) analyse the impact of nexus management on GHG emissions. There are also papers that use climate change both as in- and output, for example in the analysis of the impacts of climate change on irrigation and crop production and their implications for energy use and GHG emissions (Yan et al., 2018).

As mentioned in section 6.1, policy is often developed in to reach goals or solve problems primarily in a single sector. The nexus literature emerged from the water sector. This is reflected in the literature that often approaches the nexus from a water, agriculture or irrigation perspective; about half the studies (39/80), have a clear focus, of which only a few (7) have a starting point other than water, agriculture or irrigation.

8.3.3 Geography and scale

Nexus studies are overwhelmingly conducted on cases outside of the EU. Only 5 studies in this survey (excluding SIM4NEXUS studies) focus exclusively on the situation within the EU. 47 publications focus exclusively on case studies outside the EU, with only around ten analysing case studies both inside and out of the EU. The remaining publications are generally reviews, focus on methods without a case study or take a global perspective. The small amount of EU case studies may result from the nexus as a concept mainly serving developing countries, which were thought to be most strongly harmed by interactions between, for instance, food vs fuel trade-offs. In addition, the nexus elements show resemblance with the Millennium Development Goals WEHAB-themes (water, energy, health, agriculture, biodiversity), which were aimed at the problems in developing countries.

The scales at which the studies assess the nexus vary: Global (15), national (23), regional (30) and local (5) (where is should be mentioned that this does not imply a hierarchy; the regional scale can be larger or smaller than the national scale). Studies were categorized as global are comprised mainly of modelling studies, for example the continental scale hydro-economic model (Kahil et al., 2018) or integrated scenarios to support FEW (food, energy, water) nexus analysis (Van Vuuren et al., 2019). Other studies with a global character are mostly meta and review studies such as a review of decision making tools for efficient resource management and governance (Namany et al., 2019) and a discussing of the Nexus in description, theory and practice (Leck et al., 2015).

The bulk of the studies fit in either the national (23) or regional (30) groups. A regional scale can mean that it is a greater or a smaller scale than the national governance level. Some regional studies are supranational (like studies on cross-border river basins (e.g., (Foran et al., 2019; Stein et al., 2018)) and some are subnational (such as Simpson et al (2019) on the South African province of Mpumalanga). Regional studies are often centred around river basins or other ‘naturally’ bordered areas. Examples are the Mekong river basin (Biba, 2016; Keskinen et al., 2015; Matthews & Motta, 2015; Smajgl et al., 2016) or the Blue Nile river basin (Müller-Mahn & Gebreyes, 2019). Despite the study areas’ defining feature being natural elements, suggesting that regional studies might focus more often on water or land as a starting point, regional studies in our literature database have a starting point about as often as national studies. While the amount of studies that mention specific nexus elements are quite similar over the different scales (See Figure 9), comparing studies on a national level with regional level studies, the majority of national studies focus on land (about two thirds) as a starting point, while regional studies are more often oriented on water (about two thirds).

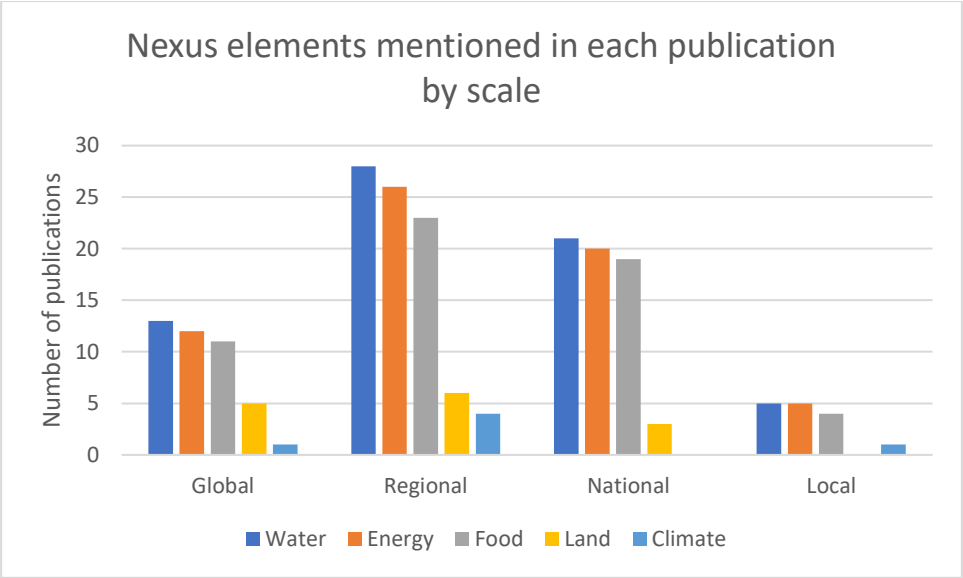

Figure 9. Nexus elements mentioned in each publication by scale (total: 84)

Regional studies more often (but not limited to) of focus on conflict and power relations, related to the transnational aspect of supra-national regional studies, or inequalities in countries. For example two studies on the Nile river basin analyse how inter-country political conflict can have negative effects on WEF resource availability (Verhoeven, 2015), and, exacerbated by pre-existing asymmetric power relations, disadvantage local people further (Gebreyes et al., 2020; Müller-Mahn & Gebreyes, 2019; Verhoeven, 2015).

The few (5) local studies are focussed on cities and ether look at specific technologies (Comino et al., 2020; Dal Bo Zanon et al., 2017; Guan et al., 2020), or focus on a stakeholder perspective (Mohtar & Daher, 2016; Treemore-Spears et al., 2016).

In general, nexus studies tend to look at the global level through a modelling and more theoretical lens, or be a meta-study covering multiple case studies in various areas globally, while the local to national level, and also supra-national studies such as those focused on river basins, are all case studies, more recognisant of the local practicalities of nexus approaches.

8.3.4 Summary: characterising the nexus literature

The eighty or so journal papers reviewed above show that the 'nexus literature' that has emerged since the first mention of the 'water-energy-food-nexus' during the World Economic Forum of 2011 consists of:

1) predominantly case studies, assessing in a particular country, region or area and using modelling or qualitative analysis to evaluate how the nexus is implemented (including a small number of studies assessing a large number of case studies);
2) modelling studies, at the global but also at the national or local level, that quantitatively indicate the overall value of regarding water, energy and food jointly;
3) theoretical work looking into integrative governance, and conceptual and definitional aspects. The latter literature generally concludes that the nexus is not fundamentally different from earlier concepts integrating sectors, like Integrated Resource and Water Management, and that it faces similar challenges.

There are very few studies that expand the WEF-nexus to 'land' and 'climate' as in the SIM4NEXUS project, but food is often integrated with land, and climate impacts and mitigation is taken into account in many water and energy assessments, respectively.

The literature is predominantly positive about the concept, but at the same time critical about its practical use so far. Many studies therefore make recommendations on the process requirements for the nexus. These are synthesised in the next section.

8.4 What factors enable and inhibit implementing the WLEFC nexus?

Modelling studies illuminate the benefits that can be reaped when nexus approaches are implemented. Case studies provide contextualised information on factors that inhibit and enable the practical implementation of WEF and other nexus approaches. This section discusses a number of often-mentioned barriers and enablers for nexus implementation, and how those barriers can be overcome according to the literature review.

8.4.1 Awareness, knowledge and capacity

A lack of awareness and knowledge of interlinkages in the WLEFC nexus is often mentioned, as well as a lack of knowledge and capacity to address the nexus. While scientific awareness and knowledge of the nexus has increased over the past few years (Figure 8), the reviewed literature suggests awareness of the nexus is lacking among policymakers. For example, in the Himalaya region (Golam et al., 2015) and Bangladesh (Gain et al., 2015), the nexus is not recognized in policy documents. Biba (2016) discusses the lack of awareness, specifically among the policy-making elite in South East Asia.

Mohtar and Daher (2016) also note that even when science has identified interlinkages between elements of the WEF nexus and policymakers are aware, policy measures addressing any conflicts have often not been implemented due to a lack of knowledge by policymakers on how to go about it. Other studies mention lacking empirical and practical knowledge of the relations between the elements of the nexus (Conway et al., 2015; Galaitsi et al., 2018; Halbe et al., 2015; Hoff et al., 2019; Leck et al., 2015; Jianguo Liu et al., 2018; Mansoor et al., 2019; Weitz et al., 2017). Middleton et al (2015) contend that while knowledge and awareness of the nexus have diffused from a global policy arena into a regional one, it is not yet grounded in national policy and practices.

Awareness and knowledge is not only crucial for policymakers in order to adopt a nexus approach, but also has a role in aligning different stakeholders or sectors. Across different sectors, awareness and knowledge, or lack thereof, with non-policymaker stakeholders can both support or hinder effectiveness of governance by causing conflicting messages, duplication of efforts, incoherent policy, lack of trust or even outright hostility (Zelli et al., 2020). Portney et al., (2018) demonstrates the need for public support through the correlation between public awareness of nexus interlinkages and support for policy measures addressing those interlinkages.

Clearly, awareness of the impact of the nexus is too low and needs increasing. Multiple authors have suggested to frame the nexus as a risk-reducing, security-enhancing activity, for instance for water security, energy security or food security (Biba, 2016; Conway et al., 2015; Hurford & Harou, 2014; Nepal et al., 2019; Rasul, 2014; Waldron et al., 2017). Also the Sustainable Development Goals (SDGs) framing can be seen as an opportunity or a policy window for the nexus approach (Bleischwitz et al., 2018; Hoff et al., 2019; Keairns et al., 2016; Nilsson et al., 2016; Simpson et al., 2019), although the effectiveness has not yet been researched. Analogously, Paim et al (2020) also suggest linking the nexus approach to the nationally determined contributions in the Paris Climate Agreement.

8.4.2 Financial support and incentives

Many studies highlight a lack of financial support for nexus elements other than the starting point as a basic barrier in policy implementation. For example, a solar-based groundwater pumping for irrigation can be an environmentally friendly and nexus-compliant solution for the energy requirements in

irrigation, but financial support is only available for the most cost-efficient irrigation (Closas & Rap, 2017). The need for rigour in examining the impacts and caution in financial support also extends to stakeholders, as demonstrated by an example of a conceptually and theoretically nexus-compliant and beneficial drip-irrigation case study in Morocco that in practice exacerbated poverty and inequality (Jobbins et al., 2015).

Sustainable use of nexus resources continues to be secondary to economic growth (Biba, 2016). Growth is linked to resource use and greenhouse gas emissions (Hack, 2015), and deteriorating nexus resources are considered often unpriced externalities (Keulertz & Woertz, 2015). The priority of economic efficiency over sustainable development is also demonstrated in a set of case studies on the Mekong river delta, where economic and political forces downplayed or disregarded nexus interactions and trade-offs (Foran, 2015; Matthews & Motta, 2015). Also in the European Investment Bank energy investments, such a pattern could be discerned (Mennen, 2020).
In addition to the availability of financial support, the placement of incentives can inhibit or enable full implementation of the nexus, in particular on smaller governance scales. There are often discrepancies between the beneficiaries and those who bear the costs of sustainable resource management (Bell et al., 2016; Hack, 2015; Hoff et al., 2019; Rasul, 2014; Sun et al., 2019). The incentives are often split; the water manager gets incentivised for solving a water problem, and the energy manager for solving an energy problem, but their combined challenge, and the combined solution that provides the highest benefit and cost efficiency overall, is not implemented. For example, individual stakeholders cannot afford solar-based groundwater pumps, despite the overall lower costs for all stakeholders combined (Closas & Rap, 2017; Jobbins et al., 2015). These imbalances can occur through the entire WEF value chain (Villamayor-Tomas et al., 2015).

In response to economic barriers in implementing the nexus approach, the literature explores several practical ways to deal with investment challenges. In a study on financial challenges of the nexus in the Arab world, Keulertz & Woertz (2015) suggest a range of instruments: a) climate finance instruments (conditional loans from industrial countries in support of climate change mitigation in adaptation), b) domestic and regional capital funds, c) increasing access to capital for development banks, d) more traditional concessionary via international financial institutions and bilateral investment agreements, and e) financing the nexus agenda in the region itself, from non-core, oil and gas-rich Gulf countries, similar to the rentier state practices in the 1970s and 1980s. Making use of these routes, however, requires a concerted effort, and will in part depend on the widespread understanding of the value of water in the region.

Such a sentiment echoes throughout the nexus literature: nexus resources are rarely valued appropriately. Placing economic value on ecosystem services is suggested as a viable way to deal with this challenge. Stakeholders and communities, especially downstream, are highly dependent on ecosystem services in sustaining WEF security (Rasul, 2014). For example, water quality and quantity also provides subservices such as biomass production (including fish) and carbon sequestration, but it is thus far not possible for those managing those resources to reap those benefits (Hülsmann et al., 2019). Ecosystem services need to be accounted for by recognising non-monetary, physical-unit constraints on ecosystem services (Conway et al., 2015; Sharmina et al., 2016).

For solving the split incentive problem, closing the loop between impacts and incentives is crucial (Bell et al., 2016). This idea recurs in nexus literature under different names, but the core of the idea is to identify those who stand to lose out from the measures, and compensate them (Allouche et al., 2014; Middleton et al., 2015; Villamayor-Tomas et al., 2015). Identifying winners and losers and compensating them also allows the nexus approach to account for environmental justice, and avoid exacerbating inequality (Allouche et al., 2014; Keskinen et al., 2015; Middleton et al., 2015).

8.4.3 Governance alignment and policy coherence

Maximising synergies and reducing trade-offs between nexus sectors make intersectoral coordination essential in a nexus approach, however a lack of policy coordination between different sectors prevails in many countries (Paim et al., 2020). In context of the nexus, governance alignment expresses itself through policy coherence. Coherent policy is logically consistent around a common goal. Nilsson et al (2012) defines policy coherence as '*an attribute of policy referring to the systematic effort to reduce conflicts and promote synergies within and across individual policy areas at different administrative/spatial scales.*'

Policy is typically developed and implemented to address a single problem or sector. According to Hoff et al (2019), sectoral silos are caused by a lack of incentives for integrated and coordinated policymaking (see also section 6.4.2). While cross-sectoral coordination mechanisms are common, coordination is weak in practice (Benson et al., 2015; UN environment, 2018). Responsibilities of policymakers are framed around those single problems or sectors, and incentives are designed with regards to achieving those goals. Impacts outside their system are not always considered, and negative impacts are not always disincentivised.

Policy coherence exists in horizontal and vertical dimensions. Horizontal policy coherence refers to the interaction of goals, means and implementation practices across multiple policy areas at the same administrative scale (e.g. water/food at EU level; water/energy/food at national level, etc.). Vertical policy coherence regards the interaction of goals, means and implementation practices between one policy area across multiple administrative scales (e.g. global/EU climate policy; global/EU/national climate policy, etc.) (Munaretto & Witmer, 2017).

A set of case studies in the MENA region shows several examples of the need for horizontal and vertical policy coherence (Hoff et al., 2019). The importance of cross-sectoral coordination is shown for example in the interaction between energy and water in drip irrigation and solar pumping policies, or in the threat of land degradation by practices defined by the water sector alone, such as irrigation in marginal lands, which in combination with fertilizer can cause salinization and other non-sustainable side effects. Villamayor-Tomas et al (2015) present another 4 studies across Germany, Spain, Kenya and India showing the need for policy coordination between not only the WEF sectors, but also vertically, detailing in a value chain and institutional analysis the roles across EU and national government, as well as irrigation districts and farmers. A clear lack of vertical policy coherence is analysed in a study on water management in China (Du et al., 2019). Here, historically, revenue and expenditure on irrigation and water conservancy projects (IWCP) were managed by the central government. In the process of decentralisation, both the revenue and responsibility for IWCP shifted to local governments. Subsequent tax reforms moved revenue back to the central government, but accountability and financial rights with regards to IWCP remained ambiguous, resulting in a lack of funding (Du et al., 2019).

In order to increase policy coherence, case studies based on interviews make a number of straightforward suggestions, such as increasing collaboration and communication (Benson et al., 2015; Daher et al., 2020), however, the question remains on how to achieve this. Case studies might answer this for specific cases. For example (Du et al., 2019) lists clarification of financial accountability in all levels of government, the creation of local non-profit organizations to enhance co-management between farmers and government and raising subsidies for the construction and management of small-scale irrigation and water conservancy projects as requirements for more coherent policy.
An analysis by Venghaus et al (2019) reveals that currently, different authorities are endowed with largely sectoral mandates. Accordingly, the respective sectoral policy sets are historically grown based on differing sets of formal and informal rules and processes, thus making policy integration among the sectors, let alone across the broader nexus, a highly challenging task. One tool is to change or align the mandate with shared policy goals. Aligning these goals with SDGs or NDCs might be useful in that

regard (Bleischwitz et al., 2018; Hoff et al., 2019; Keairns et al., 2016; Nilsson et al., 2016; Paim et al., 2020; Simpson et al., 2019).

A more challenging task would be to change the institutional framework to close governance gaps and improve policy coherence. Literature often refers to the concept of integrative governance as way to achieve this. Weitz et al (2017) identify three key gaps in literature related to governance: 1) the conditions for cross-sector coordination and collaboration; 2) dynamics beyond cross-sector interaction and collaboration; 3) political and cognitive factors as determinants for change.

In search of how to achieve this, Märker et al (2018) developed two hypothetical governance frameworks, one with increased vertical integration, and another that focusses on cross-sectoral integration. They find that both are necessary, but that the 'right' way of integrating policy highly depends on the specific case-study. An option that might be easier to implement is put forward by Soto Golcher & Visseren-Hamakers (2018). They suggest that one-way integration from stronger to weaker sectors might be an option if complexity or politics otherwise prevent integration. In the same paper they also mention soft power as an important tool in aligning institutions. Another suggestion is that a focus on sustainable innovations can close the theory–practice gap (Halbe et al, 2015). Additionally, including different stakeholders in policymaking, or even in research, such as through participatory modelling can help analyse current barriers and drivers in local context and increase cooperation. Another simple option is to reduce the number of actors, and thereby greatly increase the feasibility of cross-sector coordination (Villamayor-Tomas et al., 2015).

8.4.4 Power dynamics

A common recurring theme in nexus literature is the importance of social, political and economic power structures in the nexus. Despite the overwhelming evidence of this, politics are often ignored in favour of a more technocratic approach to the nexus (Keulertz & Woertz, 2015). Power asymmetries or power dynamics can prevent a beneficial implementation of the nexus. Allouche et al (2014) argue that power dynamics, through governance processes, determine the particular configuration interlinkages between the WEF elements of the nexus. Power dynamics describe the relative power of actors to influence or outright control other actors, and in turn resources. Asymmetries in power allow actors to exploit nexus resources in line with their own goals, disregarding negative impacts elsewhere or to the detriment of goals of other, powerless, actors. This contrasts with the core aim of the nexus approach, which aims to maximise benefits across the whole system.

Power asymmetries are often socio-political or economical in nature. The hierarchical structure between actors described by Stein et al (2018) is an example of socio-political power asymmetries. Power dynamics are not limited to state institutions. Government power can be reduced through, for example, certain types of reform (Keulertz & Woertz, 2015), but private entities and sectors can exert strong influence over weaker state governance (Meza et al., 2015; Paim et al., 2020).

The importance of power can be illustrated through sets of studies focussing on single regions. A historical study of agricultural development of the Nile river basin shows that water use and food security is at the centre of Egypt's political economy, forged and sustained through factional strife and outside interests. According to Verhoeven (2015), the economic and ecological ravages by these elite politics serves as a warning. In another case study on the of hydro developments of the Blue Nile Basin in Ethiopia spanning half a century, the importance of asymmetric power structures and their social consequences are emphasized (Stein et al., 2018) also describes how cross-sectoral relationships are intertwined with hierarchical power. It is argued by (Müller-Mahn & Gebreyes, 2019) that the WEF nexus perspective does not sufficiently capture the political nature of hydro-development, for example with regard to the causes of water scarcity and the disadvantages suffered by the local population.

There are similarities between the Nile river basin studies and the water, energy and food security challenges in the Mekong river basin. Development of hydro-power threatens water and food security at local and national scales (Biba, 2016; Keskinen et al., 2015; Smajgl et al., 2016). Matthews & Motta (2015) show how investment in hydropower in the Mekong delta is driven by foreign political and economic forces, while crafting narratives that downplay or disregard nexus interactions and trade-offs. In turn, this influences how trade-offs and interconnections in hydropower development are managed and recognised in both local and transboundary contexts, thereby, creating potentially significant negative impacts on livelihoods, food security and the environment. Foran (2015) looks at the nexus from a social science perspective, approaching the nexus as a superimposition of regimes: for example, the aggregation of sector-specific regulatory and planning practices in the WEF regimes effectively impose a net cost on poor people.

8.5 Policy recommendations and further research

8.5.1 Recommendations on governance

From Section 8.4, a number of recommendations can be derived. The first and general recommendation is that both power dynamics and governance need to be explicitly observed and monitored while acting on any nexus. More specifically, recommendations include:

- Introduce a more appealing framing of the nexus in a unifying, common way, for instance through security, the SDGs or sustainable innovation
- Promote communication and interaction between siloed policy fields and encourage them to see each other's perspective
- Pragmatic integrative governance: broaden mandates of sectoral policymakers
- Resolve split incentives by a host of instruments, such as domestic and regional capital funds, increasing access to capital for development banks or more traditional concessionary via international financial institutions and bilateral investment agreements.
- Promote vertical policy coherence through clarification of financial accountability in all levels of government, the creation of local non-profit organizations to enhance co-management between farmers and government and raising subsidies for the construction and management of small-scale irrigation and water conservancy projects
- Include stakeholders in decision-making and research on both the nexus and specific policy decisions.

8.5.2 Suggestions for further research

A lack of knowledge of nexus interactions and gaps in nexus science can partially be solved by extra research and data gathering. A lack of data on interlinkages of the nexus is mentioned by many studies (D'Odorico et al., 2018; Johnson et al., 2019; Larsen et al., 2019; J. Liu et al., 2017; Markusson et al., 2012; Said et al., 2019). However, empirical evidence of a successful nexus approach, along with practical evaluation of the implementation and contextual factors, would be of value. Reviews find it difficult to validate claims that the nexus approach has improved resource management or governance outcomes (Galaitsi et al., 2018) (Hoff et al., 2019) attempts to break the vicious cycle of presenting several case studies without the ability to draw generalisable conclusions.
In addition to these points, several authors make recommendations on the conduct and the type of research. Several highlight that multi- and transdisciplinary research is necessary (Albrecht et al., 2018), that stakeholders should be involved in the design of the research, and that modelling not based on a central social planner should be changed, as this situation is not realistic.

References

- Allouche, J., Middleton, C., & Gyawali, D (2014). Water and the Nexus Nexus Nirvana or Nexus Nullity? A dynamic approach to security and sustainability in the water-energy-food nexus. www.steps-centre.org/publications
- Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R. S. J., & Yumkella, K. K (2011). Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy*, *39*(12), 7896–7906. https://doi.org/https://doi.org/10.1016/j.enpol.2011.09.039
- Bell, A., Matthews, N., & Zhang, W (2016). Opportunities for improved promotion of ecosystem services in agriculture under the Water-Energy-Food Nexus. *Journal of Environmental Studies and Sciences*, *6*(1), 183–191. https://doi.org/10.1007/s13412-016-0366-9
- Benson, D., Gain, A. K., & Rouillard, J. J (2015). *Water Governance in a Comparative Perspective: From IWRM to a "Nexus" Approach?* Water Alternatives 8(1): 756-773.
- Biba, S (2016). The goals and reality of the water–food–energy security nexus: the case of China and its southern neighbours. *Third World Quarterly*, *37*(1), 51–70. https://doi.org/10.1080/01436597.2015.1086634
- Bleischwitz, R., Spataru, C., VanDeveer, S. D., Obersteiner, M., van der Voet, E., Johnson, C., Andrews-Speed, P., Boersma, T., Hoff, H., & van Vuuren, D. P (2018). Resource nexus perspectives towards the United Nations Sustainable Development Goals. In *Nature Sustainability* (Vol. 1, Issue 12, pp. 737–743). Nature Publishing Group. https://doi.org/10.1038/s41893-018-0173-2
- Closas, A., & Rap, E (2017). Solar-based groundwater pumping for irrigation: Sustainability, policies, and limitations. *Energy Policy*, *104*, 33–37. https://doi.org/10.1016/j.enpol.2017.01.035
- Comino, E., Dominici, L., Ambrogio, F., & Rosso, M (2020). Mini-hydro power plant for the improvement of urban water-energy nexus toward sustainability - A case study. *Journal of Cleaner Production*, *249*, 119416. https://doi.org/10.1016/j.jclepro.2019.119416
- Conway, D., Archer van Garderen, E., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Osborn, T., Ringler, C., Thurlow, J., Zhu, T., Dalin, C., & van Garderen, A (2015). *Climate and southern Africa's water-energy-food nexus Article (Accepted version) (Refereed) Original citation: Climate and southern Africa's water-energy-food nexus*. https://doi.org/10.1038/nclimate2735
- D'Odorico, P., Davis, K. F., Rosa, L., Carr, J. A., Chiarelli, D., Dell'Angelo, J., Gephart, J., MacDonald, G. K., Seekell, D. A., Suweis, S., & Rulli, M. C (2018). The Global Food-Energy-Water Nexus. In *Reviews of Geophysics* (Vol. 56, Issue 3, pp. 456–531). Blackwell Publishing Ltd. https://doi.org/10.1029/2017RG000591
- Daher, B., Hannibal, B., Mohtar, R. H., & Portney, K (2020). Toward understanding the convergence of researcher and stakeholder perspectives related to water-energy-food (WEF) challenges: The case of San Antonio, Texas. *Environmental Science and Policy*, *104*, 20–35. https://doi.org/10.1016/j.envsci.2019.10.020
- Dal Bo Zanon, B., Roeffen, B., Czapiewska, K. M., de Graaf-Van Dinther, R. E., & Mooij, P. R (2017). Potential of floating production for delta and coastal cities. *Journal of Cleaner Production*, *151*, 10–20. https://doi.org/10.1016/j.jclepro.2017.03.048
- Du, L., Xu, L., Li, Y., Liu, C., Li, Z., Wong, J. S., & Lei, B (2019). China's Agricultural Irrigation and Water Conservancy Projects: A Policy Synthesis and Discussion of Emerging Issues. *Sustainability*, *11*(24), 7027. https://doi.org/10.3390/su11247027
- Fan, X., Zhang, W., Chen, W., & Chen, B (2020). Land–water–energy nexus in agricultural management for greenhouse gas mitigation. *Applied Energy*, *265*, 114796. https://doi.org/10.1016/j.apenergy.2020.114796

- Foran, T (2015). Node and Regime: Interdisciplinary Analysis of Water-Energy-Food Nexus in the Mekong Region. *Water Alternatives*, *8*(1), 655–674. www.water-alternatives.org
- Foran, T., Penton, D., Ketelsen, T., Barbour, E., Grigg, N., Shrestha, M., Lebel, L., Ojha, H., Almeida, A., & Lazarow, N (2019). Planning in Democratizing River Basins: The Case for a Co-Productive Model of Decision Making. *Water*, *11*(12), 2480. https://doi.org/10.3390/w11122480
- Gain, A. K., Giupponi, C., & Benson, D (2015). The water–energy–food (WEF) security nexus: the policy perspective of Bangladesh. *Water International*, *40*(5–6), 895–910. https://doi.org/10.1080/02508060.2015.1087616
- Galaitsi, S., Veysey, J., & Huber-Lee, A (2018). Where is the added value? A review of the water-energy-food nexus literature SEI working paper. June 2018.
- Gebreyes, M., Bazzana, D., Simonetto, A., Müller-Mahn, D., Zaitchik, B., Gilioli, G., & Simane, B (2020). Local Perceptions of Water-Energy-Food Security: Livelihood Consequences of Dam Construction in Ethiopia. *Sustainability*, *12*(6). https://doi.org/10.3390/su12062161
- Golam, R., Sharma, B., & Rasul, G (2015). Climate Policy The nexus approach to water-energy-food security: an option for adaptation to climate change The nexus approach to water-energy-food security: an option for adaptation to climate change. *Climate Policy*, *16*. https://doi.org/10.1080/14693062.2015.1029865
- Grubb, Michael, with Jean-Charles Hourcade and Karsten Neuhoff (2014): Planetary Economics. Routledge, London, UK.
- Guan, X., Mascaro, G., Sampson, D., & Maciejewski, R (2020). A metropolitan scale water management analysis of the food-energy-water nexus. *Science of the Total Environment*, *701*, 134478. https://doi.org/10.1016/j.scitotenv.2019.134478
- Hack, J (2015). Application of payments for hydrological ecosystem services to solve problems of fit and interplay in integrated water resources management. *Water International*, *40*(5–6), 929–948. https://doi.org/10.1080/02508060.2015.1096122
- Halbe, J., Pahl-Wostl, C., A. Lange, M., & Velonis, C (2015). Governance of transitions towards sustainable development – the water–energy–food nexus in Cyprus. *Water International*, *40*(5–6), 877–894. https://doi.org/10.1080/02508060.2015.1070328
- Hoff, H., Alrahaife, S. A., El Hajj, R., Lohr, K., Mengoub, F. E., Farajalla, N., Fritzsche, K., Jobbins, G., Özerol, G., Schultz, R., & Ulrich, A (2019). A Nexus Approach for the MENA Region—From Concept to Knowledge to Action. *Frontiers in Environmental Science*, *7*(APR), 48. https://doi.org/10.3389/fenvs.2019.00048
- Hülsmann, S., Sušnik, J., Rinke, K., Langan, S., van Wijk, D., Janssen, A. B., & Mooij, W. M (2019). Integrated modelling and management of water resources: the ecosystem perspective on the nexus approach. In *Current Opinion in Environmental Sustainability* (Vol. 40, pp. 14–20). Elsevier B.V. https://doi.org/10.1016/j.cosust.2019.07.003
- Hurford, A. P., & Harou, J. J (2014). Balancing ecosystem services with energy and food security – Assessing trade-offs from reservoir operation and irrigation investments in Kenya's Tana Basin. *Hydrology and Earth System Sciences*, *18*(8), 3259–3277. https://doi.org/10.5194/hess-18-3259-2014
- Jobbins, G., Kalpakian, J., Chriyaa, A., Legrouri, A., & El Mzouri, E. H (2015). To what end? Drip irrigation and the water–energy–food nexus in Morocco. *International Journal of Water Resources Development*, *31*(3), 393–406. https://doi.org/10.1080/07900627.2015.1020146
- Johnson, N., Burek, P., Byers, E., Falchetta, G., Flörke, M., Fujimori, S., Havlik, P., Hejazi, M., Hunt, J., Krey, V., Langan, S., Nakicenovic, N., Palazzo, A., Popp, A., Riahi, K., van Dijk, M., van Vliet, M., van Vuuren, D., Wada, Y., … Parkinson, S (2019). Integrated Solutions for the Water-Energy-Land Nexus: Are Global Models Rising to the Challenge? *Water*, *11*(11), 2223. https://doi.org/10.3390/w11112223
- Kahil, T., Parkinson, S., Satoh, Y., Greve, P., Burek, P., Veldkamp, T. I. E., Burtscher, R., Byers, E., Djilali, N., Fischer, G., Krey, V., Langan, S., Riahi, K., Tramberend, S., & Wada, Y (2018). A

Continental-Scale Hydroeconomic Model for Integrating Water-Energy-Land Nexus Solutions. *Water Resources Research*, *54*(10), 7511–7533. https://doi.org/10.1029/2017WR022478
- Keairns, D. L., Darton, R. C., & Irabien, A (2016). The Energy-Water-Food Nexus. *Annual Review of Chemical and Biomolecular Engineering*, *7*(1), 239–262. https://doi.org/10.1146/annurev-chembioeng-080615-033539
- Keskinen, M., Someth, P., Salmivaara, A., & Kummu, M (2015). Water-Energy-Food Nexus in a Transboundary River Basin: The Case of Tonle Sap Lake, Mekong River Basin. *Water*, *7*(10), 5416–5436. https://doi.org/10.3390/w7105416
- Keulertz, M., & Woertz, E (2015). Financial challenges of the nexus: pathways for investment in water, energy and agriculture in the Arab world. *International Journal of Water Resources Development*, *31*(3), 312–325. https://doi.org/10.1080/07900627.2015.1019043
- Kibaroglu, A., & Gürsoy, S. I (2015). Water–energy–food nexus in a transboundary context: the Euphrates–Tigris river basin as a case study. *Water International*, *40*(5–6), 824–838. https://doi.org/10.1080/02508060.2015.1078577
- Larsen, M. A. D., Petrovic, S., Engström, R. E., Drews, M., Liersch, S., Karlsson, K. B., & Howells, M (2019). Challenges of data availability: Analysing the water-energy nexus in electricity generation. *Energy Strategy Reviews*, *26*, 100426. https://doi.org/10.1016/j.esr.2019.100426
- Lechón, Y., De La Rúa, C., & Cabal, H (2018). Impacts of Decarbonisation on the Water-Energy-Land (WEL) Nexus: A Case Study of the Spanish Electricity Sector. *Energies*, *11*(5), 1203. https://doi.org/10.3390/en11051203
- Leck, H., Conway, D., Bradshaw, M., & Rees, J (2015). Tracing the Water-Energy-Food Nexus: Description, Theory and Practice. *Geography Compass*, *9*(8), 445–460. https://doi.org/10.1111/gec3.12222
- Liu, J., Yang, H., Cudennec, C., Gain, A. K., Hoff, H., Lawford, R., Qi, J., Strasser, L. de, Yillia, P. T., & Zheng, C (2017). Challenges in operationalizing the water–energy–food nexus. *Hydrological Sciences Journal*, *62*(11), 1714–1720. https://doi.org/10.1080/02626667.2017.1353695
- Liu, Jianguo, Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., Pahl-Wostl, C., Xu, Z., Chung, M. G., Sun, J., & Li, S (2018). Nexus approaches to global sustainable development. In *Nature Sustainability* (Vol. 1, Issue 9, pp. 466–476). Nature Publishing Group. https://doi.org/10.1038/s41893-018-0135-8
- Mansoor, A., Sultana, B., Shafique, S., & Zaman, K (2019). The water-energy-food resources and environment: Evidence from selected SAARC countries. *Advances in Energy Research*, *6*(1), 1–15. https://doi.org/10.12989/eri.2019.6.1.001
- Märker, C., Venghaus, S., & Hake, J. F (2018). Integrated governance for the food–energy–water nexus – The scope of action for institutional change. In *Renewable and Sustainable Energy Reviews* (Vol. 97, pp. 290–300). Elsevier Ltd. https://doi.org/10.1016/j.rser.2018.08.020
- Markusson, N., Shackley, S., & Evar, B (2012). The social dynamics of carbon capture and storage : understanding CCS representations, governance and innovation. Earthscan.
- Matthews, N., & Motta, S (2015). Chinese State-Owned Enterprise Investment in Mekong Hydropower: Political and Economic Drivers and Their Implications across the Water, Energy, Food Nexus. *Water*, *7*(11), 6269–6284. https://doi.org/10.3390/w7116269
- Mennen, Corné, 2020. Coherence between European investments in the energy sector and the WLEFC-NEXUS. Radboud University Master Thesis. Available on: https://www.sim4nexus.eu/userfiles/MASTERTHESIS_WLEFC_NEXUS_def.pdf
- Mercure, J. F., Paim, M. A., Bocquillon, P., Lindner, S., Salas, P., Martinelli, P., Berchin, I. I., de Andrade Guerra, J. B. S. O., Derani, C., de Albuquerque Junior, C. L., Ribeiro, J. M. P., Knobloch, F., Pollitt, H., Edwards, N. R., Holden, P. B., Foley, A., Schaphoff, S., Faraco, R. A., & Vinuales, J. E (2019). System complexity and policy integration challenges: The Brazilian Energy- Water-Food Nexus. In *Renewable and Sustainable Energy Reviews* (Vol. 105, pp. 230–243). Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.01.045

- Meza, F. J., Vicuna, S., Gironás, J., Poblete, D., Suárez, F., & Oertel, M (2015). Water–food–energy nexus in Chile: the challenges due to global change in different regional contexts. *Water International*, *40*(5–6), 839–855. https://doi.org/10.1080/02508060.2015.1087797
- Middleton, C., Allouche, J., Gyawali, D., & Allen, S (2015). The Rise and Implications of the Water-Energy-Food Nexus in Southeast Asia through an Environmental Justice Lens.
- Mohtar, R. H., & Daher, B (2016). Water-Energy-Food Nexus Framework for facilitating multi-stakeholder dialogue. *Water International*, *41*(5), 655–661. https://doi.org/10.1080/02508060.2016.1149759
- Müller-Mahn, D., & Gebreyes, M (2019). Controversial Connections: The Water-Energy-Food Nexus in the Blue Nile Basin of Ethiopia. *Land*, *8*(9), 135. https://doi.org/10.3390/land8090135
- Munaretto, S., & Witmer, M (2017). Water-land-energy-food-climate nexus: Policies and policy coherence at European and International scale. SIM4NEXUS report: D2.1: https://www.sim4nexus.eu/userfiles/Deliverables/Deliverable_D2.1%20resubmission%20after%20review%20with%20annex%201.pdf
- Namany, S., Al-Ansari, T., & Govindan, R (2019). Sustainable energy, water and food nexus systems: A focused review of decision-making tools for efficient resource management and governance. In *Journal of Cleaner Production* (Vol. 225, pp. 610–626). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.03.304
- Nepal, S., Neupane, N., Belbase, D., Pandey, V. P., & Mukherji, A (2019). Achieving water security in Nepal through unravelling the water-energy-agriculture nexus. *International Journal of Water Resources Development*, 1–27. https://doi.org/10.1080/07900627.2019.1694867
- Nilsson, M., Griggs, D., & Visbeck, M (2016). Policy: Map the interactions between Sustainable Development Goals. *Nature*, *534*(7607), 320–322. https://doi.org/10.1038/534320a
- Nilsson, M., Zamparutti, T., Petersen, J. E., Nykvist, B., Rudberg, P., & McGuinn, J (2012). Understanding Policy Coherence: Analytical Framework and Examples of Sector-Environment Policy Interactions in the EU. *Environmental Policy and Governance*, *22*(6), 395–423. https://doi.org/10.1002/eet.1589
- Paim, M.-A., Salas, P., Lindner, S., Pollitt, H., Mercure, J.-F., Edwards, N. R., & Viñuales, J. E (2020). Mainstreaming the Water-Energy-Food Nexus through nationally determined contributions (NDCs): the case of Brazil. *Climate Policy*, *20*(2), 163–178. https://doi.org/10.1080/14693062.2019.1696736
- Portney, K. E., Hannibal, B., Goldsmith, C., McGee, P., Liu, X., & Vedlitz, A (2018). Awareness of the Food–Energy–Water Nexus and Public Policy Support in the United States: Public Attitudes Among the American People. *Environment and Behavior*, *50*(4), 375–400. https://doi.org/10.1177/0013916517706531
- Rasul, G (2014). Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region{star, open}. *Environmental Science and Policy*, *39*, 35–48. https://doi.org/10.1016/j.envsci.2014.01.010
- Said, M., Komakech, H. C., Munishi, L. K., & Muzuka, A. N. N (2019). Evidence of climate change impacts on water, food and energy resources around Kilimanjaro, Tanzania. In *Regional Environmental Change* (Vol. 19, Issue 8, pp. 2521–2534). Springer. https://doi.org/10.1007/s10113-019-01568-7
- Sharmina, M., Hoolohan, C., Bows-Larkin, A., Burgess, P. J., Colwill, J., Gilbert, P., Howard, D., Knox, J., & Anderson, K (2016). A nexus perspective on competing land demands: Wider lessons from a UK policy case study. *Environmental Science and Policy*, *59*, 74–84. https://doi.org/10.1016/j.envsci.2016.02.008
- Simpson, G. B., Badenhorst, J., Jewitt, G. P. W., Berchner, M., & Davies, E (2019). Competition for Land: The Water-Energy-Food Nexus and Coal Mining in Mpumalanga Province, South Africa. *Frontiers in Environmental Science*, *7*(JUN), 86. https://doi.org/10.3389/fenvs.2019.00086

- Smajgl, A., Ward, J., & Pluschke, L (2016). The water-food-energy Nexus - Realising a new paradigm. *Journal of Hydrology*, *533*, 533–540. https://doi.org/10.1016/j.jhydrol.2015.12.033
- Soto Golcher, C., & Visseren-Hamakers, I. J (2018). Framing and integration in the global forest, agriculture and climate change nexus. *Environment and Planning C: Politics and Space*, *36*(8), 1415–1436. https://doi.org/10.1177/2399654418788566
- Stein, C., Pahl-Wostl, C., & Barron, J (2018). Towards a relational understanding of the water-energy-food nexus: an analysis of embeddedness and governance in the Upper Blue Nile region of Ethiopia. *Environmental Science and Policy*, *90*, 173–182. https://doi.org/10.1016/j.envsci.2018.01.018
- Sun, J., Li, Y. P., Suo, C., & Liu, Y. R (2019). Impacts of irrigation efficiency on agricultural water-land nexus system management under multiple uncertainties—A case study in Amu Darya River basin, Central Asia. *Agricultural Water Management*, *216*, 76–88. https://doi.org/10.1016/j.agwat.2019.01.025
- Talozi, S., Al Sakaji, Y., & Altz-Stamm, A (2015). Towards a water–energy–food nexus policy: realizing the blue and green virtual water of agriculture in Jordan. *International Journal of Water Resources Development*, *31*(3), 461–482. https://doi.org/10.1080/07900627.2015.1040544
- Treemore-Spears, L. J., Grove, J. M., Harris, C. K., Lemke, L. D., Miller, C. J., Pothukuchi, K., Zhang, Y., & Zhang, Y. L (2016). A workshop on transitioning cities at the food-energy-water nexus. *Journal of Environmental Studies and Sciences*, *6*(1), 90–103. https://doi.org/10.1007/s13412-016-0381-x
- UN environment (2018). Progress on integrated water resources management. Global baseline for SDG 6 Indicator 6.5.1: degree of IWRM implementation.
- Van Vuuren, D. P., Bijl, D. L., Bogaart, P., Stehfest, E., Biemans, H., Dekker, S. C., Doelman, J. C., Gernaat, D. E. H. J., & Harmsen, M (2019). Integrated scenarios to support analysis of the food–energy–water nexus. *Nature Sustainability*, *2*(12), 1132–1141. https://doi.org/10.1038/s41893-019-0418-8
- Venghaus, S., Märker, C., Dieken, S., & Siekmann, F (2019). Linking Environmental Policy Integration and the Water-Energy-Land-(Food-)Nexus: A Review of the European Union's Energy, Water, and Agricultural Policies. *Energies*, *12*(23), 4446. https://doi.org/10.3390/en12234446
- Verhoeven, H (2015). The nexus as a political commodity: agricultural development, water policy and elite rivalry in Egypt. *International Journal of Water Resources Development*, *31*(3), 360–374. https://doi.org/10.1080/07900627.2015.1030725
- Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., & Kimmich, C (2015). The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks. *Water Alternatives*, *8*(1), 735–755.
- Waldron, A., Garrity, D., Malhi, Y., Girardin, C., Miller, D. C., & Seddon, N (2017). Agroforestry Can Enhance Food Security While Meeting Other Sustainable Development Goals. *Tropical Conservation Science*, *10*, 194008291772066. https://doi.org/10.1177/1940082917720667
- Weitz, N., Strambo, C., Kemp-Benedict, E., & Nilsson, M (2017). Closing the governance gaps in the water-energy-food nexus: Insights from integrative governance. *Global Environmental Change*, *45*, 165–173. https://doi.org/10.1016/j.gloenvcha.2017.06.006
- Yan, T., Wang, J., Huang, J., Xie, W., & Zhu, T (2018). The impacts of climate change on irrigation and crop production in Northeast China and implications for energy use and GHG Emission. *Proceedings of the International Association of Hydrological Sciences*, *379*, 301–311. https://doi.org/10.5194/piahs-379-301-2018
- Zelli, F., Bäckstrand, K., Nasiritousi, N., Pattberg, P. H., Sanderink, L., Skovgaard, J., van Asselt, H., & Widerberg, O (2020). Analytical Framework: Assessing Coherence, Management, Legitimacy and Effectiveness in an Institutional Nexus. In *Governing the Climate-Energy Nexus*. Cambridge University Press.

– Zheng, J., Wang, W., Chen, D., Cao, X., Xing, W., Ding, Y., Dong, Q., & Zhou, T (2019). Exploring the water–energy–food nexus from a perspective of agricultural production efficiency using a three-stage data envelopment analysis modelling evaluation method: A case study of the middle and lower reaches of the Yangtze River, China. *Water Policy*, *21*(1), 49–72. https://doi.org/10.2166/wp.2018.184