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The Land-Water-Energy Nexus and the Sustainability of the Food System

This Reader was prepared by

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The Land-Water-Energy Nexus and the Sustainability of the Food System

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1. Context

A significant part of the global population still lacks access to adequate energy, water and food systems, with more than 1.06 billion people lacking access to electricity[1] and half of those people live in sub-Saharan Africa.

The planet's natural resources are increasingly coming under pressure and suffering depletion with impacts on ecosystems in many places. Increasing demand due to population growth and economic development combined with unsustainable production methods will put increased strain on the natural resources base that is unlikely to be reversed during the foreseeable future. Climate Change brings additional challenges to the Water, Energy and Food (WEF) complex because it affects resource availability (quality and quantity) and ecosystems.

Population growth projections estimate that the global population will have grown up around to 9 billion by 2050. Therefore, energy consumption is estimated to grow by 80% and food demand by 60%.[2] Agriculture is already consuming 70% of all global freshwater abstractions.[3] Economic growth and middle-income living result in increased demand for water, food, and energy as a consequence of consumption patterns. Per capita consumption of animal food has been increasing in the last few decades. Dairy and meat production are expected to increase by 65% and 76%, respectively, by 2050.[4]

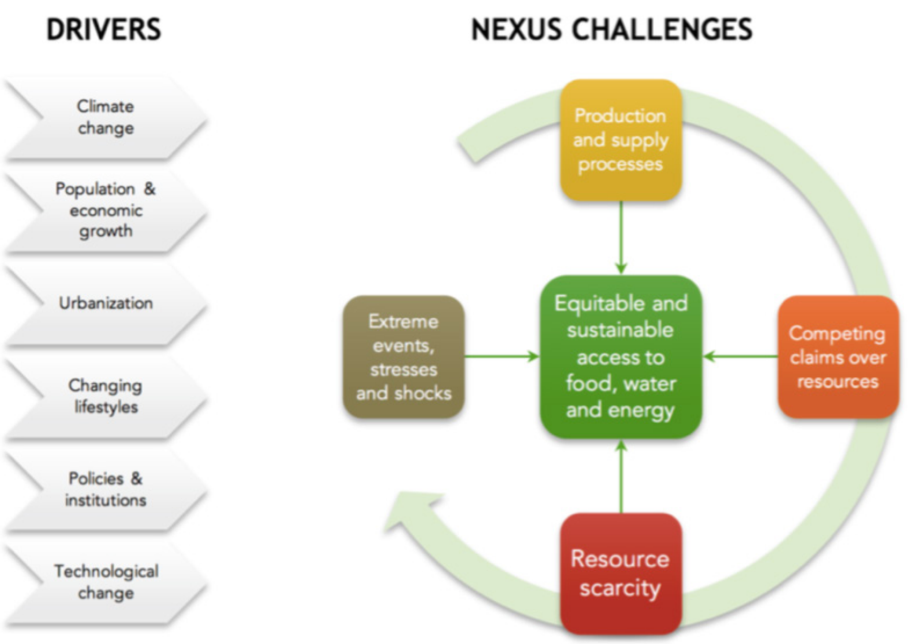
Irrigation will have to play an important role in increasing food production. Growth in agricultural production to feed a projected human population of over 9 billion in 2050 will come from increasing crop yields, and expanding arable land area, together with increases in cropping intensities.

By 2050, according to most baseline scenarios, the demand for energy will nearly double, along with population and economic growth, while water and food demand is expected to increase by over 50%. These dynamics are combined with major trends in climate change, land use change and the depletion of natural resources, which already limit the ability of systems to meet growing demands, and threaten sustainable development and food, water and energy security in many places of the world. Interactions between water, energy and food systems are manifold.

Energy is required to process and distribute water, water is central for nearly all forms of energy production, and both energy and water are key to any food enterprise.

The requirement of energy and water for food is expected to be exacerbated soon as 60% more food will be required to be produced in order to feed the world in 2050 and global energy consumption is projected to grow by close to 50 percent by 2035.[5] In Africa a five-fold increase in power capacity is expected by 2040 (6% per annum is expected to sustain a continental annual average economic growth rate of 6.2% over this period and an annual energy demand growth rate of 5.7% taking into account the potential for energy efficiency gains).[6]

Water-Energy-Food Nexus challenges



Source: Future Earth (2018), Research and Engagement Plan for the Water-Energy-Food Knowledge-Action Network, Report of the Development Team.

The Land-Water-Energy Nexus and the Sustainability of the Food System

Global energy demand is projected to increase 35% by 2035. Meeting this rising demand could increase water withdrawals in the energy sector by 20%, and water consumption in the sector by 85%.[7]

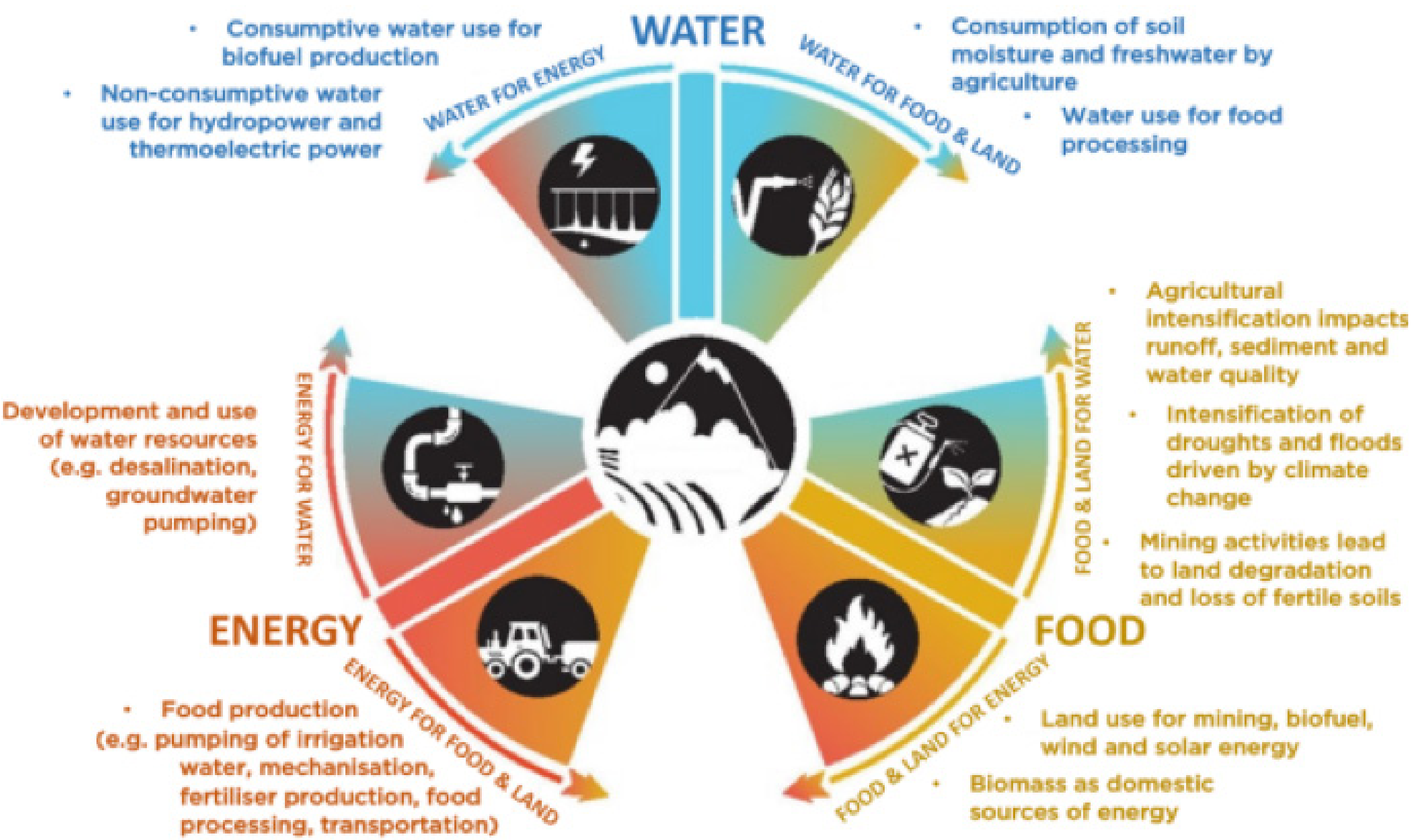
Growing pressures on natural resources are making the interdependencies and trade-offs between food, water and energy systems, and their interactions with land, climate change and livelihoods, increasingly evident. Agriculture is the largest consumer of the world's freshwater resources, and more than one-quarter of the energy used globally is expended on food production and supply.[8]

As a result, pursuing one security objective (i.e. food, water or energy security) may be to the detriment of the others, and reflects the challenge of competing claims over limited natural resources.

Vulnerabilities in water and energy supply pose critical risks for food security, as severe droughts and fluctuations in energy prices can affect the availability, affordability, accessibility and utilisation of food over time. The agro-food supply chain accounts for 30% of the world's energy consumption and is the largest consumer of water resources, accounting for approximately 70% of all freshwater use. Such interlinkages are compelling governments, the private sector, communities, academia and other stakeholders to explore integrated solutions to ease the pressures and formulate development pathways based on sustainable and efficient use of limited resources.[9]

Existing or anticipated threats to equitable and sustainable access to energy, water and food are due to the modes of production and consumption of resources and pressures due to poverty and scarcity or conflict; competition on use of land and impact of climate change.

Connections between water, energy and food systems.



Source: Future Earth (2018), Research and Engagement Plan for the Water-Energy-Food Knowledge-Action Network, Report of the Development Team.

2. The Nexus Thinking: Definition and approaches

2.1. Background

The Water-Energy-Food Nexus discourse started at the Bonn 2011 Conference: "The Water, Energy and Food Security Nexus: Solutions for the Green Economy" presenting evidence on how a nexus approach could enhance water, energy and food security.

In May 2012, the 2011/2012 EU Development Report (ERD) "Confronting scarcity: Managing water, energy and land for inclusive and sustainable growth"[10] was launched ahead of the Rio+20 Conference. The Report urged the international community to radically transform approaches to managing water, energy and land (WEL) in order to support inclusive and sustainable growth in the poorest developing countries. The Rio+20 Conference also made gender equality and women's empowerment, water security and sustainable water management, food security and agricultural development priorities for sustainable development.

Bonn 2011 paved the way for "Berlin 2013: Realizing the Water, Energy and Food Security Nexus" which took stock of progress made in the conceptual development and the implementation of the nexus perspective and discussed new ways of anchoring the water, energy and food security nexus in global, regional and national policies. One of the main findings of the Policy Forum was the relevance of regional cross-sectorial dialogue processes led by regional organisations and the need to focus on specific policy issues in order to tackle cross-sectorial bottlenecks.

Water-food-energy connections lie at the heart of sustainable, economic and environmental development and protection. The demand for all three resources continues to grow for various reasons: a growing population, ongoing population movements from farms to cities, rising incomes, increased desire to spend those incomes on energy and water intensive goods/varying diets, international trade, urbanization and climate change.

Water being a finite resource, but also the most abundant resource of the three sectors is the most exploited. Water is primarily used in forestry and fishery, agricultural production and agri-food supply chain and is used to create and/or transfer energy in varying forms.

Agriculture is the largest user of freshwater, making it responsible for 70% of total global withdrawal, while more than one fourth of energy used worldwide is an input for food production, distribution, and use. In addition, food production and supply chain simultaneously utilize approximately 30% of the total energy that is used globally. The greater the capacity to pay for improved water, the more it will enable alternative water sources, such as desalination to bring water into urban areas from greater distances, such as desalinated seawater often requiring energy-intensive production and transport methods. Countries, food, water and energy industries, as well as other users can agree that the increasing use of more water, energy and land resources (food) have a great potential to face issues with environmental deterioration and even resource scarcity, as we can already see taking place in some parts of the developing world. The unbroken links between these sectors.[11]

2.2. Definition

The WEFE Nexus is an approach that integrates management and governance across the multiple sectors of food, energy, water, and ecosystems.

The WEF nexus is a systems-based perspective that explicitly recognizes water, energy, and food systems as both interconnected and interdependent.[12]

By considering how water, energy, and food systems operate and interact, the nexus approach aims to maximize synergies (mutually beneficial outcomes) and minimize trade-offs (which may potentially include non-optimal outcomes), improve resource-use efficiency, and internalize social and environmental impacts, particularly across a range of contexts and scales.[13] The underlying aims are to strengthen cross-sectoral integration and improve management outcomes to enhance water, energy, and food security.[14]

The **water, energy and food security nexus** according to the Food and Agriculture Organization of the United Nations (FAO), means that water security, energy security and food security are very much linked to one another, meaning that the actions in any one particular area often can have effects in one or both of the other areas. These three sectors (water, energy and food security nexus) are necessary for the benefit of human well-being, poverty reduction and sustainable development.[15]

The Nexus corroborates the need to not view water, energy, food. and ecosystems as being separate entities, but rather as being complex and inextricably entwined. Globally as well as locally, there is a growing realisation of the interconnectedness between Water, Energy, Food Security, and Ecosystems.

Direct inputs of water are needed in the production of food and energy while energy is required for the storage and distribution of food as well as in water extraction, conveyance, and treatment. Natural resources and ecosystems services also underlie water, food, and energy security. Any limitation in one of the inputs would disturb the availability of one of the others. Applying the WEFE Nexus approach helps to improve understanding of the interdependencies across sectors and the Ecosystems with a view to improving integrated solutions in the field that improve achievement of SDGs. The Nexus approach is a way of ensuring more integrated and sustainable use of resources that both reaches beyond the traditional silos and can be applied at all scales.[16]

Many nexus studies focus on dual-sector interactions, e.g. water-food or water-energy. Because of the water-centric nature of the nexus in many studies, researchers have found that 'current Nexus analyses are insufficiently cross-sectoral'[17] to improve coordination of policies across resource sectors and reduce unintended trade-offs and impacts among water, energy, and food security, all key elements of the sustainable development agenda.

To identify, understand, and analyse interconnections and interdependences among water, energy, and food systems, there is a need for all three sectors to be considered together, and equally, through an integrated analysis[18]. Furthermore, the complexity of developing cross-sectoral management and policies demands attention to the socio-political context of these systems.[19]

The interactions between water, energy and food in a nexus approach are crucial for the implementation of the United Nations (UN) *Sustainable Development Goals* (SDGs). Out of the total seventeen SDGs (Griggs et al., 2013, UN, 2015), three of them have a focus on water, energy and food1. Accordingly, SDG#2 aims at fighting hunger and malnutrition. SDG#6 aims at providing access to safe water and sanitation as well as ensuring a sound management of freshwater ecosystems. SDG#7 promotes energy access for all and supports actions to meet targets for increased share of renewable energy sources' (RES) use and high levels of energy efficiency (EE).

2.3. Principles

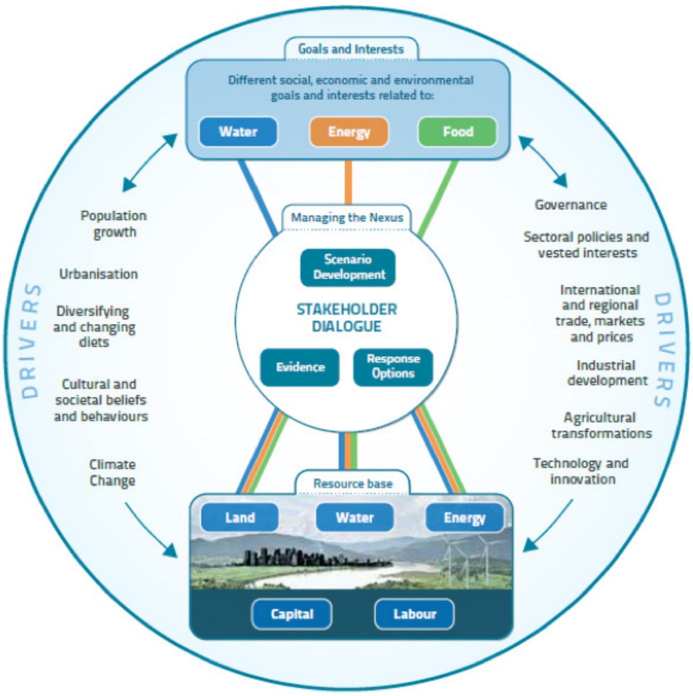
The Nexus is a step beyond single sector planning towards a more holistic approach to planning. Although it will still take years of research and test-implementation before reaching a fully mainstreamed into cross-sectorial planning processes, multi-sectorial dialogues leading to intervention projects successfully addressing concrete multi-sectorial issues and needs are already a reality.

The key principles of the WEFE Nexus are:[20]

- Understand the interdependence of resources within a system across space and time and focus on the whole system's efficiency rather than the productivity of individual components. This will provide integrated solutions that contribute to the sustainability of water, energy, food security policy objectives and to maintaining healthy ecosystems.

- Recognize the interdependence between water, energy, food and ecosystems and promote

FAO approach to WEFE Nexus



Source: FAO. 2014. The Water-Energy-Food Nexus. A new approach in support of food security and sustainable agriculture.

rational and inclusive dialogue and decision-making processes and efficient use of these resources in an environmentally responsible way.

- Identify integrated policy solutions to optimise trade-offs and maximise synergies across sectors and encourage mutually beneficial responses that enhance the potential for cooperation between all components, and public–private partnership at multiple scales.

- Ensure coordination across sectors and stakeholders to enable synergies and increase solution sustainability. The nexus approach requires a multidisciplinary and cross sectoral approach as well as close collaboration between researchers, practitioners and decision-makers.

- Value the natural capital of land, water, energy sources and ecosystems and encourage governments and business to support the transition to sustainability, e.g., using nature-based solutions.

There is a need to consider the importance of **local context and social dynamics**[21], **collaborative** and **participatory approaches**, to apply flexibility in the approach to allow tailored methods to various geographic regions and to incorporate new knowledge.

The WEF nexus can serve in multiple roles—as an analytical tool, a conceptual framework, or a discourse.[22] The WEF nexus has been applied to analyse particular resource issues, including irrigation, ethanol production, hydropower, forestry, desalination, and bioenergy.[23] Recent research on the WEF nexus addresses food commodity chains, including transport and cooling, end-consumers, and waste and effluent management[24] . WEF nexus studies also contribute conceptual accounts for trade-offs inherent in decisions to grow crops for biofuels or for food.[25]

2.4. Challenges in implementation of the Nexus approach

Despite the large body of literature on the concept and the many research projects applying the concept, there is an ongoing discussion on how to best transfer the concept from a theoretical framework to be implemented on the ground.

The conceptualization has not been accompanied by coordinated development of a comprehensive set of tools and methods for analysis and quantification. Instead, methods have largely been borrowed or adapted from conventional disciplinary approaches, e.g. efficiency analysis based on engineering process studies, economic supply-chain and commodity-chain analyses, and agronomic soil-plant water assessments.[26]

Nexus literature acknowledges that a Nexus approach requires coordination and integration across levels of government (vertical), as well as across sectors (horizontal) and emphasises the key role of institutional relationships and effective coordination mechanisms.[27]

Although the need for cooperation is recognised, there are several barriers to the adoption of a WEF Nexus approach in decision making, due to the complexity of interrelationships between sectors and governance levels. A lack of communication between the sectors, divergent sectoral institutional frameworks and interests as well as unequal distribution of power and capability between sectors are identified as barriers in numerous studies.

To strengthen the coordination between sectors, the adaptation of existing governance arrangements rather that creation of new or ideal arrangements is often discussed. Numerous studies recommend using existing procedures and legislatives in order to identify institutional mechanisms for Nexus implementation, which would be adapted to the regional institutions and bureaucracies.[28]

2.5. Evaluation of the WEF Nexus interconnections

Recently, many analysis frameworks and methodologies have been introduced to facilitate a better understanding of the WEF Nexus. Different methodologies have varying data requirement, benefits and limitations, and some only operate at geographical scales.[29] Data and information availability are of paramount importance, as without them, the most important Nexus interactions cannot be properly identified. The FAO developed an approach to address the synergies and interlinkages between human and natural resources. It focuses on the resource base, including the biophysical and socio-economic resources, as a basis for addressing the Nexus between water, energy and food securities.

Data access and sharing

Data availability and accessibility is a key challenge for a nexus assessment. The challenge is relevant for specific sectors (e.g., data on water use or energy production) as well as across sectors (e.g., data on water use for energy production). When data are available, they are scattered, have limited comparability with other data sets, cover different scales (e.g., local, national, regional) or do not provide temporal trends. » Most nexus tools are designed for a thorough analysis of the three sectors with a view to quantifying trade-offs, while considering the applicable resource constraints. Hence, such tools have significant data and resource needs, but can be highly effective in informing decision making that is sensitive to the nexus. » Preliminary or rapid assessment tools are of increasing importance. Such tools, which could precede a more comprehensive analysis, are relatively less data and resource intensive, and can provide inputs within a timeframe that is in line with the policy-making process.[30]

Nexus Assessment initially requires data and knowledge collection to identify the linkages between the water, energy, and food systems, and the impact that changes to these systems can have on the ecosystems and livelihoods.

There is often a lack of good, accurate, harmonised, and up-to-date knowledge, data, and information; asymmetrical access to information; available data and knowledge in transboundary basins may differ greatly in terms of level of aggregation, scale, accuracy, reliability, etc. not only between countries sharing resources but also institutions.

Sharing of information between Institutions involved in data and knowledge collection and management needs to be encouraged as information on critical conditions in one sector impact the other. This is particularly important in the case of transboundary waters.

There is a general need to improve data collection across the different sectors and scales. In the particular case of biophysical data where ground data is particularly lacking, remote sensing has been highlighted as a means of bridging and supplementing this gap, at least in certain thematic areas. Field surveys can also be used as ways of collecting local and traditional knowledge that would complement biophysical and socio-economic data and a way to concretise what the real issues are. This is key to supporting decision making in terms of food security, poverty reduction, sustainable basin management, and inclusive development.

Open-source models and open-access platforms combining spatial data have been well received in low- and middle-income countries where license costs and governmental au-thorisation may be difficult to overcome or obtain. However, insufficient data and models available should not be a stumbling block or a reason for not using the Nexus approach until data and models are ideal.

3. The Nexus: a tool for policymaking

Nexus policymaking is about designing resilient strategies in ways that take account of the connections between food, water and energy systems. It starts with recognition of the interdependence of those systems, and hence challenges single-sector approaches that can have substantial unintended consequences for a country's future development options. As well as managing those kinds of risks, it points towards opportunities for each country to make the most of its mix of resource endowments, systematically aligning its development with the possibilities inherent in that mix.[31]

Adopting a nexus approach to sector management involves analysing cross-sectoral interactions to facilitate integrated planning and decision making. Such an approach encompasses the use of a vast array of quantitative and qualitative decision support tools and methodologies depending on the purpose of the analysis, access to data and availability of technical capacity (SEI, 2013). The outcomes from such tools inform policy making by quantifying the extent to which a certain policy affects the different sectors. The need for such integrated decision-support frameworks is illustrated, for example, by the FAO's nexus assessment methodology.

Methodologies to support nexus-friendly decision making can be qualitative, quantitative or combined.

As part of its contribution to the Nexus HIO, the FAO has developed the WEF nexus assessment methodology (FAO, 2014b). The goal of this methodology is: 1) to have an idea of the sustainability of the reference system/territorial context (e.g., a country or a region) and its bio-economic pressures, and 2) to assess the performance of specific policy- or project-level interventions in terms of natural and human resource-use efficiency. It is supported by qualitative and/or quantitative assessment; identification of response options needed to ensure the sustainability of the environment and livelihoods; adequate stakeholder engagement at every relevant step.[32]

3.1. WEF Nexus Initiatives[33]

Multiple initiatives have been implemented across the globe to inform about, promote and implement a WEF Nexus approach in addressing resource securities.

The Nexus Regional Dialogues[34]

Programme 2 Phase 1 of the Nexus Regional Dialogues Programme is funded by the EU and BMZ and runs from 2016 to 2018. The programme aims to develop Nexus policies and action plans at the national ministerial and regional policy levels and is implemented in five regions (MENA, Latin America, Niger Basin, Central Asia and Southern Africa). This programme manages the Water Energy & Food Security Resource Platform[35], which was launched at the Bonn Nexus conference in 2011 and provides up to date information on events, publications and projects from around the world. It is the most comprehensive information hub on the WEF Nexus (Nexus Platform, n.d.).

WEF Nexus as a High Impact Opportunity in the Sustainable Energy for All Initiative[36]

Sustainable Energy for All (SEforALL) is a global initiative launched by former UN Secretary General Ban Ki-Moon to advance action on SDG 7 (Ensure access to affordable, reliable, sustainable and modern energy for all). Part of the SEforALL is the High Impact Opportunities (HIOs) platform which engages all stakeholders in action areas that have significant potential to further the SEforALL objectives. The HIOs platform has adopted the WEF Nexus approach as a high-impact opportunity to guide the planning and implementation of projects (SEforALL, 2018).

WEF Nexus in the World Bank's Thirsty Energy Initiative[37]

Thirsty Energy is an initiative launched by the World Bank to face the challenges of the water and energy resources planning, by helping countries consider water constraints when planning in the energy sector. The initiative uses a Nexus approach in identifying synergies and trade-offs between water and energy in planning and use, piloting water-smart energy planning tools, enhancing governments' decision-making coordination, spreading awareness on water-energy challenges, and fostering multi-stakeholder dialogue. Case studies which developed and piloted water-smart energy planning tools were carried out in South Africa, China and Morocco (World Bank Group, 2018).

UNECE Task Force on the Water-Food-Energy-Ecosystems Nexus[38]

The United Nations Economic Commission for Europe (UNECE) mandated the establishment of the Taskforce to carry out thematic assessments on WEF-Ecosystems Nexus in transboundary basins. It addresses issues including low coherence and absence of integration between policies of various sectors, which negatively impact the conditions of shared waters. The Taskforce pursues efforts to enhance long-term WEF security and the transition to a green economy. A pilot project was undertaken in the Alazani / Ganykh basin (shared by Azerbaijan and Georgia) and the taskforce has carried out assessments of the Sava, Syr Darya, Isonzo / Soča and Drina river basins (UNECE, 2018).

WEF Nexus Dialogue on Water Infrastructure Solutions[39]

The International Union for Conservation of Nature (IUCN) and the International Water Association (IWA) have jointly launched an initiative in 2012 to address the demand competition over water resources across the WEF sectors. It aims to provide multi-sectoral solutions through infrastructure, up-to-date technology and investing in Ecosystem services. The initiative has held workshops in Africa, Latin America and Asia (Ozment et al., 2015).

WEF Nexus in the USAID Grand Challenges for Development on Water, Food and Energy[40]

The Grand Challenges for Development is a United States Agency for International Development (USAID) initiative to bring together governments, companies and foundations to solve development issues through innovative solutions, testing new ideas and up-scaling successful pilot projects. Two out of the 10 challenges launched build on the Nexus approach: Powering Agriculture Challenge which aims to bring clean energy for agriculture; and the Securing Water for Food Challenge which promotes technology and scientific innovation to boost food production using less water (USAID, 2018).

3.2. The nexus in the context of EU development policy

The European Union (EU) has long recognised the importance of the nexus between water, energy, food and ecosystems (WEFE). The 2017 European Consensus on Development underlines the EU commitment to support an integrated approach that concretely addresses the most relevant interlinkages between land, food, water and energy. If appropriately taken into consideration, these interlinkages can increase efficiency, reducing trade-offs and building synergies while improving governance across sectors.

In 2015, the European Commission's Directorate-General for International Cooperation and Development (DG DEVCO), together with the German Federal Ministry for Economic Cooperation and Development, launched the "Nexus Dialogues" programme. This aims to support the development of national and regional policy recommendations that consider the links between the WEFE sectors. The European Commission's Joint Research Centre (JRC), which is strongly engaged in WEFE projects to inform the efficient implementation of sustainable growth measures, provides important scientific support to this programme.[41]

The EU financed "Nexus Dialogues" in collaboration with the German Government has two phases (phase I 2016-2018) proposes to strategically steer on-going and newly established demand-driven Nexus policy-dialogue approaches in five regions: Africa (Nile, Niger and SADC), Latin America (Andean region), Asia (Mekong Area), Central Asia (Aral Sea region) and the Neighbourhood (with particular focus on the Mediterranean region).

As a result of this programme, governments and organisations are expected to make improvements to existing policy discourse and more efficient and inclusive long-term policy. The Nexus Dialogues should not mean a duplication of effort; the action should fit within existing regional programmes and platforms as appropriate and bring a stronger Nexus brief to on-going discussions. This action will also finance support studies, building up teams of nexus experts from the countries/regions, small-pilot projects and an evaluation and a feasibility study to guide Phase II will be on leveraging of investment projects.

In recent years, EU regional programmes for **Latin America** have given specific and substantive attention to the promotion of sustainable development and poverty reduction through programmes and projects to combat the effects of climate change, promote renewable energy and improve water management.[42]

4. Sustainable solutions and technological innovations

The increased global demand for land is creating increased tension among competing needs at the global, national and local level. The rising demand for food and energy competes for productive land. This underlines the importance of increasing land productivity in ways that encourage growth that is also sustainable and inclusive.[43]

4.1. Energy solutions

A combination of drivers, including energy security, climate change mitigation, socio-economic considerations and energy access, will propel the ongoing transformation of the energy sector away from traditional fossil fuel options.

Fossil fuel production, still a dominant and growing part of the global energy mix, is highly water intensive, as is biofuel production and the growing practice of shale gas. There is a need to support less water-intensive renewable energy, such as hydropower and wind. Geothermal energy has also a great potential as a long-term, climate independent resource that produces little or no greenhouse gases and does not consume water.[44]

In an increasingly water-constrained environment, renewable energy could offer a low-carbon and less water-intensive path to expanding the energy sector. While the cumulative benefits are estimated to be positive, due attention is necessary to assess the water impacts of individual technology solutions. Whereas solar PV and wind have minimal water needs, technologies such as CSP and bioenergy development could have a substantial water footprint that needs to be adequately considered in energy sector planning.[45]

Renewable energy technologies, such as solar, wind and tidal, could address some of the trade-offs between water, energy and food, bringing substantial benefits in all three sectors. They can allay competition by providing energy services using less resource-intensive processes and technologies, compared to conventional energy technologies.

Renewable energy is seen as a reliable alternative to meeting growing energy demand for water pumping and conveyance, desalination and heating, while ensuring the long-term reliability of water supply. Solar-based pumping solutions offer a cost-effective alternative to grid- or diesel-based irrigation pump sets. Large-scale deployment of solar pumps can support the expansion of irrigation, reduce dependence on grid electricity or fossil fuel supply, mitigate local environmental impacts and reduce government subsidy burdens. Recognising these benefits, several countries have launched programmes to promote solar pumping.[46]

Renewable energy-based **desalination technologies** could play an increasing role in bridging the water gap. In the Middle East and North Africa (MENA) region, one of the most water-scarce regions in the world, water shortages by 2050 will be met mostly through desalination.

The role of **off-grid solutions** e.g., for water pumping or desalination in breaking the fossil-fuel economic dependency, including as applied to food security. Off-grid solutions to satisfy energy and water needs are also found to be cost effective at local scale (e.g. farm scale).

Bioenergy, however, could necessitate substantial water inputs depending on feedstock production. **Residue-based bioenergy** requires relatively less water compared to dedicated energy crops — whose water consumption in turn depends on whether irrigation is necessary and, if so, on the irrigation method adopted, the crop type, local climatic conditions and technology choices.[47]

In some cases, bioenergy can provide a localised solution to transform rural economies while enhancing energy and food security. Intercropping Gliricidia (a fast-growing, nitrogen-fixing leguminous tree) with maize in Malawi or with coconut in Sri Lanka is substantially improving yields of agricultural products while also providing sustainable bioenergy feedstock. Such an integrated food-energy industry can enhance food production and nutrition security, improve livelihoods, conserve the environment and advance economic growth.[48]

Substituting traditional biomass for cooking with modern fuels is imperative for social and economic development. Cooking is an energy-intensive activity, especially in developing countries where inefficient cooking practices are commonplace. Around 2.7 billion people rely for cooking on traditional biomass, such as fuelwood, crop residues and animal dung, which are not always sustainably produced and lead to smoke and other emissions that can be detrimental to health. Moreover, traditional biomass is often foraged, which demands considerable labour and time, particularly affecting women. Local modern bioenergy resources, where available, can be used to improve access to modern energy services while also meeting on-site energy demand for electricity and heating in the rural economies.[49]

Some sustainable energy interventions:[50]

- Energy can be saved and used more efficiently adopting technologies that also make efficient use of water resources.
- Irrigation systems can increase water-efficiency and energy-efficiency at the same time (e.g. drip irrigation)
- Reduction of water losses and management improvements in water utilities leads to less energy consumption to pump, lift and transport water
- By improving the productivity of rain-fed agriculture, energy-intensive irrigation can be limited or reduced
- Reduction of use of non-renewable energy in agrifood systems has usually a positive effect on economic returns of food production in the long run
- The use of animal waste and manure for biogas production increases the overall energy efficiency of meat production, while providing a low-cost source of fertilizers that can help increasing yields in a sustainable manner
- Improved cooking efficiency is needed
- Increase in efficient use of energy for cook stoves and technology for food preparation and conservation increases quality of food.
- New technologies and practices can reduce the use of non-renewable energy in agro-food systems while maintaining a stable food production
- Transporting food for long distance usually implies a less energy efficient food chain (with associated GHG emissions) but can help to mitigate domestic food price volatility

4.2. Water solutions

The demand for food is growing with population expansion, and there is a significant global move away from a mainly starch-based diet to an increasing demand for more water-intensive meat and dairy as incomes grow in many countries.

Agriculture is the biggest user of water. While the shift to biofuels is generally welcomed, their production could demand as much water as fossil fuels.

Achieving water security requires investments in both the hydraulic and the institutional infrastructure needed to store, convey and manage water effectively. Where water resources are more intensively used, investment in management and institutions for resolving allocation tensions and trade-off s is a priority, particularly at the agriculture-urban-environment interface. In this context there is a fundamental need for investment in allocation planning, the development of modern systems of water rights that define shares of available resources for different users and uses, and judicious use of regulatory and market instruments to allocate water in a transparent, equitable and efficient manner.[51]

Efficiency measures along the entire agrifood chain can help save water and energy, such as precision irrigation based on information supplied by water providers, which can motivate farmers to invest in their systems to ensure the best returns from their water investment.

Consumption can be reduced, and supplies made more reliable, by such practices as using multiple water sources, including rainwater harvesting and wastewater reuse, and only treating water to be ready for its intended use, rather than treating all water to a safe drinking standard.

Currently, large quantities of water are lost each year as a result of poor application of irrigation technologies and techniques, limited capacity for water harvesting, and limited use of reusable water resources. As irrigation practices and technologies are brought to scale, it is important that they be designed to use water efficiently and prudently, to preserve the natural resource base on which agriculture depends.

Expanding countries' irrigation potential can improve agricultural productivity on existing land and extend growing seasons throughout the year, which would reduce poverty, food insecurity, and import dependency across the continent. Key lessons can be drawn from successful interventions in several African countries that can be adopted and brought to scale across the continent. The Malabo Montpellier Panel[52] identifies the most important institutional innovations as well as policy and program interventions that can be replicated and scaled up by other countries to develop and expand irrigation systems.

Agriculture in Africa is predominantly rain-fed, and those farmers who irrigate their farms primarily rely on traditional methods such as surface water diversion and rainwater harvesting, rope-and-bucket, pedal pumps, motor pumps, and rope-and-washer pumps. Examples from Kenya show that incomes can be increased by up to six-fold with use of **small-scale irrigation techniques**.

Micro dosing of inputs such as fertilizer, pesticides, or water is a highly efficient technique that minimizes the application of and overreliance on inputs. Micro dosing involves the application of small quantities of inputs onto or close to the seed or plant. Drip irrigation is a method of water micro dosing, applying a limited about of water directly where it is most needed, reducing waste and evaporation.

Drip irrigation systems can improve soil moisture conditions, resulting in yield gains

“Smart” irrigation technology combinations can control water and fertilizer supply through mobile technologies or use solar energy to pump water.

Solar technology in combination with pumping systems for irrigation is a more environmentally friendly alternative to motorized pumps, with lower maintenance costs.

5. Digitalisation supporting efficient use of resources

Technology can help to boost smallholders' revenues and contribute to the sustainability of the agricultural and rural sectors by reducing waste, encouraging renewable energy solutions.

Mobile-phone-based systems can facilitate an efficient use of different irrigation technologies, for example when combined with solar drip irrigation schemes, providing timely and precise irrigation without the farmer having to be physically present. Not only can these technologies help facilitate the management and control of agricultural processes and allow for greater flexibility and efficiency, but they may also attract young people to agriculture.

Some companies are designing irrigation systems in combination with a mobile app. The Nigerian National Space Research and Development Agency (NASDRA) recently unveiled its solar-powered automated irrigation system. The technology comes in combination with a soil sensor and a solar-powered water pump and uses signals from a navigation satellite. The system has been tested on different soil types and crop varieties. Soil conditions and moisture are measured constantly and reported back to the farmer on a mobile phone or laptop. Once the soil moisture falls below a certain threshold, the pump is automatically triggered. Similar systems have been designed by scientists at Kenya's Meru University of Science and Technology.[53]

Soil sensor technologies

Soil moisture predictions are a good tool to assess the progress of growing season conditions and can provide early warning of natural hazards, including droughts and floods. A new generation of soil sensor technologies is currently being developed for the African market. Some companies, such as Zenvus, have started selling electronic soil sensor technologies that are equipped with GPS, micro-SD and Wi-Fi for use on smartphones or laptops. These technologies help monitor data such as soil moisture and nutrients, pH and humidity levels, temperature, and sunlight, helping to increase knowledge of ongoing changes in the field and the environment; they also provide real-time guidance, recommendations and notifications on rainfall and droughts. One sensor can cover up to three hectares of land, depending on environmental factors.[54]

Although the adoption of mobile technologies is growing rapidly in SSA, most smallholder farmers do not have access to laptops or smartphonesvi, and unless prices decrease substantially, most smallholders will be unable to afford these soil sensors.

Biosensing technologies

Biosensing in food production, food processing, safety and security, food packaging and supply chain, food waste processing, food quality assurance, and food engineering.

In recent years, active and intelligent food packaging technologies offer sustainable safety and quality of foods, real-time monitoring packaging process, and improved shelf-life to meet increasing demands from manufactures and consumers. In food packaging, nanomaterials are incorporated for biosensing, increase shelf life (antimicrobial properties), and intelligent and robotic technologies to educate and alert the consumer for food safety and quality.[55]

Hyperspectral imaging camera

With the technology of hyperspectral imaging, information on electromagnetic spectrums can be collected. Zenvus in Nigeria is making the first effort to distribute such cameras, which can analyse images and identify stressed crops, droughts, and outbreaks of pests and diseases. In combination with soil sensors, farmers can use this technology to evaluate the effectiveness of their irrigation and fertilizer application by correlating soil data with overall vegetative crop health. The camera is available in two different versions, one to be mounted on a stick and one optimized to work with drones to monitor larger farms.[56]

Digital payments

Mobile money, such as Kenya's transfer system **M-Pesa**, has helped boost financial inclusion for people who didn't have a bank account by letting users treat their phone like a wallet and send money using text message. Mobile money has helped poor households gain access to a range of services by enabling users to use its platform to pay for services ranging from solar energy to bike-sharing.

Reducing water waste with digital solutions

Water scarcity is a major problem for many on the African continent. Some start-ups are trying to use technology to promote more efficient water use. One such is **HydroIQ**, a virtual water network operator which links water utility companies with consumers through an online platform. It lets users pay with mobile money and uses sensors that relay information about water leaks and consumption.

Internet of Things (IoT)

The Internet of Things is the process of giving an online identity and virtual personality to all the physical objects that surround us. Giving a digital identity to an electro valve, a LED feature or a pump may not be viewed as revolutionary but upon reflection, it does raise serious challenges to security, privacy and transparency in decision making. Following an Internet of Things approach, such objects would independently and autonomously make decisions based on certain conditions, without human intervention.

The big advantage of using an Internet of Things system is that it takes into account the environment within which it operates by collecting data from multiple sources, such as sensors, external systems (like open weather data) and users, in simpler and more cost-effective ways than traditional automation or monitoring systems such as Supervisory Control And Data Acquisition or Programmable Logic Controllers did in the past. In addition, Internet of Things systems can exploit data more effectively since they can be trained to identify issues based on pattern recognition and proactively notify operators when critical thresholds are about to be reached.

The INCOVER project, a H2020 collaboration that demonstrates "Innovative eco-technologies for Resource Recovery from Waste-water," explores how the Internet of Things concept could be used to rationalise irrigation while, at the same time, facilitating the implementation of the water, energy and food nexus.[57]

The platforms and technologies offered by the Internet of Things could have a profound role in quantifying, visualising and sharing important data that would help state and non-state actors to plan, develop and maintain sustainable economic activities. The Internet of Things can offer innovative and valuable insights like predictive analytics for irrigation, water and food waste patterns and even sharing their data with cross-sectorial domains to deliver novel services to multiple stakeholders.

Machine learning for energy-water nexus[58]

Recent technological advancement has allowed the production of large volumes of data and statistical and machine learning techniques can help elucidate characteristic patterns across water availability, transport, and use to energy generation, fuel supply, detection of water leaks in water distribution.

Machine learning provides better techniques in understanding these links of energy, water, and climate, and efficiently analyse and predict future estimates on water and energy availability through observing data related to climate change and water-energy system interactions. Although, at this point, it might look useful to follow various machine learning approaches, it is always important to consider the challenges and issues that could hinder in making progress to applying machine learning in energy-water nexus. Below are some of the challenges that machine-learning researchers may face in tackling problems relating to predicting, analysing or visualizing the water and energy system interdependencies.

6. The way forward

A nexus perspective increases the understanding of the interdependencies across the water, energy and food sectors and influences policies in other areas of concern such as climate and biodiversity. The nexus perspective helps to move beyond silos that preclude interdisciplinary solutions, thus increasing opportunities for mutually beneficial responses and enhancing the potential for cooperation between and among all sectors.

A deep understanding of the nexus will provide the informed and transparent framework that is required to meet increasing global demands without compromising sustainability. The nexus approach will also allow decision-makers to develop appropriate policies, strategies and investments, to explore and exploit synergies, and to identify and mitigate trade-offs among the development goals related to water, energy and food security. Active participation by and among government agencies, the private sector and civil society is critical to avoiding unintended adverse consequences. A true nexus approach can only be achieved through close collaboration of all actors from all sectors.

While the opportunities provided by the nexus perspective and the consequent social, environmental and economic benefits are real, implementation requires the right policies, incentives and encouragement, and institutions and leaders that are up to the task, as well as frameworks that encourage empowerment, research, information and education. Accelerating the involvement of the private sector through establishing and promoting the business case for both sustainability and the nexus is essential to driving change and getting to scale.[59]

Maintaining sustainable supplies of water and energy for future generation is the significant challenge in energy water nexus. Due to increasing competition for limited water and energy resources, it is important for the decision and policy makers to act in a prudent manner while formulating policies and decisions on managing these resources.

The importance of establishing a Nexus Cooperation Framework at multi-sectorial, country, or transboundary levels from assessment to resource- or benefit-sharing agreements is recognised.

Strengthening institutions and ensuring flexibility in the management of water, energy and agricultural land resources (through coherent development planning) enables countries to adapt to evolving development needs and uncertain climate futures. This is closely related to the requirement for robust water, energy, agricultural and transport infrastructure to support economic production and household access, within the context of limited financial and human resources.[60]

Training in applying the Nexus approach must specifically address the intervention level and its challenges (transboundary, national, regional, and local), and associated with capacity building actions especially in less developed regions/organised sectors. Professionals in each sector need to know more about and understand the thinking and methods applied in the other sectors.

The report[61] from SAB Miller – *WWF on The Water-Energy-Food Nexus: Insights into Resilient Development* looked at 16 countries, comparing the ways in which their development patterns have managed their different mixes of resources and different capacities to make use of those resources. Nexus issues play out very differently in contexts with differing resource endowments, and this is only partially determined by the climate and physical availability of natural resources in a country.

They suggest policymakers should:

- Integrate all aspects of development planning, ensuring that water, energy and agricultural sector planning are not done in isolation, but consider how each can contribute to the resilience of the others;
- Design institutions for resilience, in ways that strengthen cooperation and coordinated decision-making;
- Use economic and regulatory instruments to strengthen the incentives and requirements for building resilience into water, food and energy systems;
- Use trade, regional integration and foreign policy to manage nexus trade-offs more effectively and contribute further to resilience at both country and global levels.

Acronyms

AfDB
African Development Bank

BMZ
German Federal Ministry for Economic Cooperation and Development

CC
Combined cycle

CCS
Carbon capture and storage

CO2
Carbon dioxide

C-Si
Crystalline silicone

CSP
Concentrated solar power

CT
Combustion turbine

CAPEX
Capital Expenditure

DNI
Direct normal irradiance

EC
European Commission

ED
Electrodialysis

EE
Energy Efficiency

EGS
Enhanced geothermal system

EJ
Exajoule

EU
European Union

EWEA
European Wind Energy Association

FAO
Food and Agriculture Organization of the United Nations

FC
Fuel Cost

GHG
Greenhouse gas

GW
Gigawatt

GWh
Gigawatt-hour

GWP
Global Water Partnership

GWth
Gigawatt-thermal

IEA
International Energy Agency

IFPRI
International Food Policy Research Institute

IoT
Internet of Things

IPCC
Intergovernmental Panel on Climate Change

IRENA
International Renewable Energy Agency

IWA
International Water Association

IWRM
Integrated Water Resources Management

IWMI
International Water Management Institute

JRC
EC Joint Research Centre

kW
Kilowatt

kWh
kilowatt-hour

LCOE
Levelised Cost of Energy

MW
Megawatt

NBA
Niger Basin Authority

OECD
Organisation for Economic Co-operation and Development

p.u.
Per unit

PV
Photovoltaic

PVWPS
Photovoltaic Water Pumping System

R&D
Research and Development

RES
Renewable Energy Sources

RET
Renewable Energy Technologies

SDGs
UN Sustainable Development Goals

SPIS
Solar powered irrigation systems

TVC
Thermal vapour compression

TWh
Terawatt-hour

WEF
Water–Energy–Food nexus

WEFE
Water–Energy–Food–Ecosystems nexus

WEL
Water, Energy and Land

WRI
World resources Institute

Glossary

Active solar energy technologies
convert sunlight into space heating, hot water or electricity by utilizing an energy transfer fluid such as water or air.

Air-water heat pumps
An air source heat pump (ASHP) is a heating and cooling system that uses outside air as its heat source and heat sink.

Alternative fuels, known as non-conventional or advanced fuels, are any materials or substances that can be used as fuels, other than conventional fuels. Conventional fuels include fossil fuels, as well as nuclear materials such as uranium and thorium, as well as artificial radioisotope fuels that are made in nuclear reactors. Some well-known alternative fuels include biodiesel, bio alcohol, chemically stored electricity, hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil, and other biomass sources.

Anthropogenic climate change
Synonyms: AGW, anthropogenic global warming, man-made climate change. Human activities are adding greenhouse gases, particularly carbon dioxide, methane and nitrous oxide, to the atmosphere, which are enhancing the natural greenhouse effect. While the natural greenhouse effect is keeping average temperature on earth at about +15°C, this enhanced greenhouse effect is leading to a dangerous degree of global warming. A fast rise in average temperature of Earth could result in rising sea levels, melted glaciers, floods, droughts and other hazardous scenarios. Therefore mitigation and adaptation to anthropogenic climate change is so important.

Barrage tidal power
Tidal power, sometimes called tidal energy, is a form of hydropower that converts the energy of tides into electricity or other useful forms of power.

Biodegradable waste
Synonyms: organic waste, compostable waste.
Biodegradable waste is a type of waste which can be broken down, in a reasonable amount of time, into its base compounds by micro-organisms and other living things, regardless of what those compounds may be. Biodegradable waste can be commonly found in municipal solid waste (sometimes called biodegradable municipal waste, or BMW) as green waste, food waste, paper waste, and biodegradable plastics. Other biodegradable wastes include human waste, manure, sewage, and slaughterhouse waste. In the absence of oxygen, much of this waste will decay to methane by anaerobic digestion.

Biodiesel
Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl esters. Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat) with an alcohol producing fatty acid esters. Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used alone or blended with petrodiesel. Biodiesel can also be used as a low carbon alternative to heating oil. The National Biodiesel Board (USA) also has a technical definition of "biodiesel" as a mono-alkyl ester.

Bioenergy
Energy from sustainable sources such as forests and agriculture (like wood and energy crops), but also manure and other biodegradable wastes. Includes biogas, biofuels and solid biomass.

Bioethanol
Ethanol, also called ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol, is a volatile, flammable, colourless liquid. Ethanol is abbreviated as EtOH, using the common organic chemistry notation of representing the ethyl group (C_2H_5) with Et. Bioethanol is a readily available, clean fuel for combustion engines made from plant-based feedstock.

Biofuels from algae
Algae-based biofuels are a promising bioenergy source because algal biofuels have the additional advantage of higher yields and less demand for arable land over traditional biofuels.

Biogas
Biogas is a flammable gas that accrues from the fermentation of biomass in biogas plants.

Biogas typically refers to a gas produced by the breakdown of organic matter in the absence of oxygen. It is a renewable energy source, like solar and wind energy. Furthermore, biogas can be produced from regionally available raw materials and recycled waste and is environmentally friendly and CO_2 neutral. Biogas is produced by the anaerobic digestion or fermentation of biodegradable materials such as manure, sewage, municipal waste, green waste, plant material, and crops.

Carbon cap
Cap and trade are an environmental policy tool that delivers results with a mandatory cap on emissions while providing sources flexibility in how they comply. Successful cap and trade programs reward innovation, efficiency, and early action and provide strict environmental accountability without inhibiting economic growth.

Carbon capture and storage
A process consisting of separation of carbon dioxide from industrial and energy-related sources, transport to a storage location, and long-term isolation from the atmosphere. (IPCC).

Carbon credits
Carbon credits provide a way to reduce greenhouse effect emissions on an industrial scale by capping total annual emissions and letting the market assign a monetary value to any shortfall through trading.

Carbon footprint
Greenhouse gas accounting describes the way to inventory and audit greenhouse gas (GHG) emissions. A corporate or organisational greenhouse gas (GHG) emissions assessment quantifies the total greenhouse gases produced directly and indirectly from a business or organisation's activities. Also known as a carbon footprint, it is a business tool that provides information with a basis for understanding and managing climate change impacts. (Wikipedia)

Climate risk analysis
Climate risk analysis is a process that considers management options to minimise negative impacts and take advantage of opportunities considering the identified current and future risks.

Ecosystem services
Humankind benefits in a multitude of ways from ecosystems. Collectively, these benefits are known as ecosystem services. Ecosystem services are regularly involved in the provisioning of clean drinking water and the decomposition of wastes. While scientists and environmentalists have discussed ecosystem services implicitly for decades, the ecosystem services concept itself was popularized by the Millennium Ecosystem Assessment (MA) in the early 2000s.This grouped ecosystem services into four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits. To help inform decision-makers, many ecosystem services are being assigned economic values.

Energy crops
Energy plants are plants that get cropped or felled to produce electrical or thermal energy.

Energy efficiency
Using less energy/electricity to perform the same function. Programs designed to use electricity more efficiently - doing the same with less.

Energy security
The uninterrupted availability of energy sources at an affordable price". While there is no single definition of the concept of energy security, it has evolved from a narrow link to the stable supply of oil products to integrate other energy sources, as well as the essential dimension of sustainability.

Food security
When all people, always, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Geothermal energy
Also known as geothermal power. Heat that is stored inside the earth is transformed into electrical energy by geothermal power plants. This form of energy is considered to be cost-effective, reliable and friendly to the environment.

Green growth
Green growth means promoting economic growth while reducing pollution and greenhouse gas emissions, minimising waste and inefficient use of natural resources, and maintaining biodiversity. Green growth means improving health prospects for populations and strengthening energy security through less dependence on imported fossil fuels. It also means making investment in the environment a driver for economic growth. Green growth will require a shift in both public and private investments, with the limited public funds available carefully targeted and accompanied by the right policy frameworks to help leverage private financing.

Grid-connected photovoltaic systems
Grid-connected photovoltaic systems are connected to the public grid through an inverter and feed-in electricity into the public grid.

Hydropower
Hydro power is electrical energy produced through the power of moving water. Power obtained from the (typically gravitational) movement of water.

Low carbon development
A low-carbon economy (LCE), low-fossil-fuel economy (LFFE), or decarbonised economy is an economy that has a minimal output of greenhouse gas (GHG) emissions into the environment biosphere, but specifically refers to the greenhouse gas carbon dioxide.

Low emission development strategies
LEDS will enable countries to transition to low carbon economic development resulting in sustained growth in employment and investment, increased financial flows through carbon markets, reduced greenhouse gas (GHG) emissions, and other social, economic, and environmental benefits.

Marine energy
Marine power plants use energy from the ocean; types of ocean energy are marine current power, ocean thermal power, osmotic power, tidal energy and wave energy.

Methanol cook stoves
This technology could be applied in households and other places in developing countries where people still rely on inefficient, air polluting traditional use of biomass for their basic energy needs.

Microgrids
Micro-grids are useful to harness local renewable energy resources near-by consumption. Often a good solution for remote, previously off-grid areas.

Photovoltaic feed-in tariffs
A Feed-in Tariff is an incentive structure to encourage the adoption of renewable energy through government legislation. The regional or national electricity utilities are obligated to buy renewable electricity at above-market rates set by the government

Photovoltaic power plants
A photovoltaic plant is a power station that generates electrical power by using photovoltaic cells; usually such a power plant feeds electricity into the public grid.

Smart grids
A smart grid is an electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

Solar photovoltaic
Photovoltaics (PV) is the field of technology and research related to the application of solar cells for energy by converting sunlight directly into electricity. Solar power is sometimes used as a synonym to refer to electricity generated from solar radiation.

Tidal energy
Tidal power, sometimes called tidal energy, is a form of hydropower that converts the energy of tides into electricity or other useful forms of power.

Virtual Water
Virtual water refers to the total amount of water needed for food production which changes from country to country depending on agriculture practices.

Water-energy-food nexus
The Water, Energy and Food Nexus takes a holistic approach that takes into consideration the trade-offs that exits between water, energy and food and tries to overcome traditional silo-thinking.

Water security
The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.

Sources: IRENA, EC, OECD,FAO, SEI, UN, WRI, WB

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