EKLIPSE

Knowledge & Learning Mechanism
on Biodiversity & Ecosystem Services

EU renewable energy policies, global biodiversity, and the UN SDGs

A report of the EKLIPSE project

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- The research assistant who carried out the literature review process and created the resulting model drafted the workshop notes and contributed to report drafting, Alexis Meletiou.
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Glossary

Term	Definition
CAP	Common Agricultural Policy
EC	European Commission
EKLIPSE	EKLIPSE EU Horizon 2020 project
EU	European Union
FCM	fuzzy cognitive mapping
GHG	greenhouse gas
LCA	Life Cycle Assessment
LHP	large-scale hydropower
Mtoe	million tonnes of oil equivalent
MS	EU Member state
NGO	non-governmental organization
O&M	operation and maintenance
PHS	pumped hydropower storage
PV	photovoltaic
RED	Renewable Energy Directive
RES	renewable energy sources
RET	renewable energy technology
RoR	run-of-the-river
SDGs	Sustainable Development Goals

Term	Definition
SSH	small-scale hydropower
SSA	sub-Saharan Africa
toe	tonne oil equivalent
WEF	water-energy-food nexus
WFD	Water Framework Directive (2000/60/EC)

Executive Summary

The EU is committed to tackling the issue of climate change, which has potentially serious consequences for the global environment and human wellbeing. This report presents the results of an EKLIPSE request to assess the impacts of EU renewable energy policies on overseas biodiversity and the UN Sustainable Development Goals (SDGs). We summarise key EU policies, their supporting technologies, and known impacts on biodiversity and the SDGs, based on a review of the literature. We present a conceptual model of these impacts developed from an expert workshop using a Fuzzy Cognitive Mapping approach. Our findings highlight that RES have complex and at times disparate effects on biodiversity and the SDGs, but benefit the SDGs on balance, particularly climate-related SDGs. Mitigation of biodiversity impacts remains a concern, and policy-makers must focus on implementing appropriate environmental impact assessments, in order to limit effects such as habitat loss.

In 2018, the revised Directive on the promotion of renewable energy sources ('RES Directive') came into force, setting a binding EU target of 32% of final energy consumption from RES by 2030, with a view to further increasing this target. The revised RES Directive follows the launch of the 2016 European Commission Clean Energy package, designed to increase clean energy production in the EU Member States and meet commitments in the Paris Agreement. In the next few years, RETs are set to transform the EU electricity sector. In several EU Member States, this will involve unprecedented increases in RET power capacity, largely due to with mass deployment of utility-scale solar photovoltaic (PV) and wind power systems. Modern offshore ocean energy installations are expected, but their scale, parameters and environmental impacts are not yet clear due to their lower maturity. The development of sustainable hydropower is expected to utilize the remaining EU potential of onshore waters, mainly in run-of-river and small-scale stations. Pumped hydropower storage will provide utility-scale energy storage services, absorbing the variable energy output of modern RES. Geothermal energy stations will utilize the untapped energy of groundwater aquifers. However, there is growing concern about the displacement of environmental RET impacts on overseas territories. This is challenging to document and may disproportionately impact disadvantaged populations, affecting the attainment of the SDGs.

In this EKLIPSE request, we examined the possible impacts of this transition on biodiversity and the SDGs. Our report provides a detailed description of EU renewable energy policies, with a particular focus on relevant Directives (section 1). We examine key technologies associated with EU RE production, i.e., solar, wind, marine, hydro, geothermal, bioenergy, batteries production and electro-mobility, and the corresponding effects on biodiversity and the SDGs, particularly overseas effects (section 2). We also explore biofuel production as well as the role of interconnections and energy markets.

We first carried out an extensive literature review to collate the existing scientific evidence on the environmental effects of RET deployment and the SDGs. We then organized a two-day expert workshop on these impacts (19-20 November 2018). The 19 participants were drawn from

academic and scientific research organizations, policy-makers, the private sector, and NGOs. The findings outline the role of RES and identify challenges, based on the extensive experience of the participants. Best practices and integrated approaches are also highlighted to suggest ways to overcome and/or mitigate the impact of potential challenges.

The participants developed conceptual models of the complex system involving the support of EU RES policies for particular technologies, the processes through which these affect various aspects of biodiversity and each of the SDGs. They assessed these interactions in terms of positive or negative effects, as well as according to their relative strengths, using a Fuzzy Cognitive Mapping approach. We then integrated these individual models into a single model, allowing us to compare the relative, cumulative impacts of RETs on biodiversity and the SDGs. Our key message is that **incorporating telecoupling effects into EU energy policy can support staying within the safe zone in Europe while avoiding transgressing it elsewhere**. The 2030 Agenda puts into perspective the safe zone between the ceiling imposed by nature and the floor imposed by social equity; according to this, all countries are developing countries because they transgress either ceiling or floor.

1. Background

While a renewable energy transition is necessary for decarbonisation, it has documented effects on marine ecosystems, avian biodiversity, competition with land use for food production, habitat loss, and deforestation, with potential spillovers beyond the EU territorial boundaries. Other trade-offs may occur such as manufacturing hazards due to a growing demand for extractive resources needed in the fabrication of batteries and solar panels. The role of renewable energy sources in supporting a fossil fuel free future is controversial, due to these associated pressures on landscapes, biodiversity, and ecosystems in Europe and beyond. It is clear that conventional energy sources likewise have impacts on global biodiversity and ecosystem services. The full costs and benefits of renewable energy sources must be compared to the opportunity costs of renouncing conventional sources. Our approach to this involves collating existing knowledge in this domain.

The request informs the 2019 Global Report on the UN Sustainable Development Goals. The Global Sustainable Development Board addresses various perspectives of the SDGs, identifying how the SDG Report can help policy actors to achieve their agendas, and to move towards greater policy coherence.

Aims and objectives

This EKLIPSE activity aims to synthesise knowledge on the effect of low-carbon energy policy on biodiversity and ecosystem services beyond the EU boundaries. This information will provide a better understanding of the current mechanisms by which energy policy interconnects with biodiversity and ecosystems services. As such, it seeks to inform policy makers, scientists, UN state members on the above issues and provide policy-oriented solutions to anticipate and mitigate these issues.

In light of the above objectives, the request addresses two major questions:

1. What are the SDG targets that the EU energy policy tries to pursue (including indirectly) and what are the systemic trade-offs and co-benefits that are created beyond the territorial boundaries, where, at what scale, and who are the affected winners and losers?
2. What policies and governance mechanisms could remedy these impacts; or in hindsight, how could one have chosen pathways to more sustainable development?

Methodological approach

The approach generally followed the proposal outlined in the request's Document of Work[1]: an assessment of the relevant EU policies and an expert workshop to construct an integrated model of the complex system in which EU policies support RES with environmental and human impacts, using Fuzzy Cognitive Mapping to assign weights to these impacts. Some methods differed from those originally envisaged: we did not draft an initial model ahead of the workshop, due to time constraints. Instead, in parallel, we carried out a non-systematic literature review and created a second model based on this. This parallel process informed our understanding of the system and provided a comparison to the integrated model. While non-systematic, this review also provided further access to the scientific literature on impacts. We did not assess the feasibility of a pairwise comparison approach to assessing the links between model terms/concepts, recognising that the limited workshop time would likely prohibit this. The review is presented in Sections 2 and 3, the workshop in Section 4, and the integrated model in Section 5. Individual models are included in Appendix IV, and the model based on the review in Appendix VI. A diagram of the process followed is presented in Figure 1.

[1] http://www.eklipse-mechanism.eu/apps/Eklipse_data/website/EKLIPSE_DoW_energy_request_19Sep2019.docx

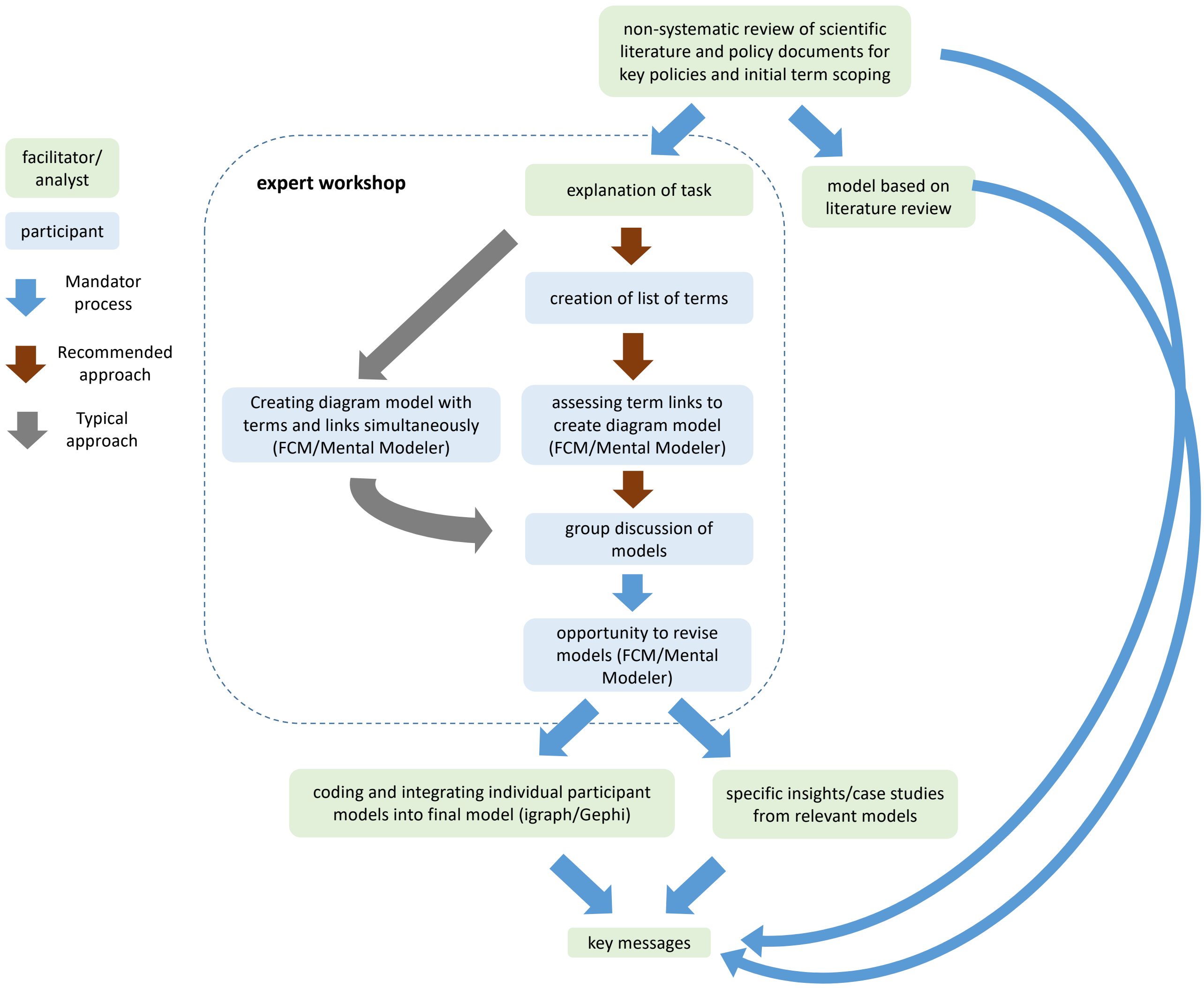

Figure 1: Diagram of the process followed to synthesise knowledge for this request. The two main approaches were a non-systematic literature and policy review for background, and an expert workshop using Fuzzy Cognitive Mapping to derive individual models of the system which were integrated into a single model. Due to time constraints, participants generally created their individual models with both terms and links simultaneously rather than first creating a list of terms and then assigning links.

Information on impacts for the review was obtained through searches used to identify relevant scientific articles based on terms relevant to renewable energy technologies and the UN Sustainable Development Goals. We searched the EC JRC literature database[2], ScienceDirect[3], the European Commission websites[4] the Politecnico di Torino (POLITO)[5] shared database literature articles and Google Scholar, in which we typically examined the first 500 hits for each search string. Further up-to-date information on EU policy developments was obtained from the European Commission webpages on renewable energy[6] and the

[2] See http://publications.jrc.ec.europa.eu/repository/
[3] Key journals: Utilities Policy Journal, Energy Policy Journal, Solar Energy, Energy Economics, The Electricity Journal, Renewable and Sustainable Energy Reviews.
[4] See https://ec.europa.eu/info/energy-climate-change-environment_en, https://ec.europa.eu/info/statistics_en, https://ec.europa.eu/info/food-farming-fisheries_en.
[5] See http://www.biblio.polito.it/en/resources/electronic_resources
[6] See https://ec.europa.eu/energy/en/topics/renewable-energy and the links to individual sections

EURACTIV website[7]. The review process and the construction of the model it underpins were designed and carried out by Alexis Meletiou.

The models of the system of interacting components were constructed by assessing the linkages between each component. The linkages are coded using a scoring system based on fuzzy cognitive mapping (FCM), in which links are assigned a score (directed), see e.g. (Özesmi and Özesmi 2004). These scores vary between -3 and 3, building on the methodology developed by the International Council for Science (ICSU Scoring scale, see Griggs et al. 2017). At +3, the parent node strongly reinforces the child node, and at -3, the parent node strongly opposes it. A score of 0 indicates neutral interaction. All participant models and the literature-based model were constructed in Mental Modeler, a freely available web-based tool[8] (Gray et al. 2013).

The integration process consisted of resolving the individual models into a single model. This model was generated from twelve of the participants' individual models. These were chosen based on the ease of integration and clear links to policy, biodiversity and SDG impacts. In two cases the model was not received in time for the integration; it is anticipated that these will be integrated into an updated version of the model for subsequent outputs. Integration focussed on developing common key terms across the models, which reduced the complexity of the final model. Similar nodes were identified and combined where possible. The majority of the participants did not focus on detailed impacts on individual biome types, so this information was not used to discriminate between otherwise very similar nodes. This information was preserved for use in developing the case studies. Interactions were adjusted in terms of the final impacts on SDGs so that they had either "positive" or "negative" impacts on achieving the SDGs. The updated individual graphs were exported as CSV files. These were imported into R (R Core Team 2018) and combined to generate the base graph using the igraph package (Csardi 2006), with the weight of each link computed as the mean of the corresponding link across the twelve models. This graph was then exported into Gephi (Bastian et al. 2009) for advanced visualisation.

2. Review of key EU energy policies

2.1 Global de-carbonization of the power sector

Global energy consumers receive 81% of all marketed energy from fossil fuels (World Bank 2017). The current discourse around energy consumption is driven by three different motivations:

- Fossil fuels are a finite resource.[9]
- There is a need for greater energy security.
- Fossil fuels have an impact on climate change.

It is recognized that anthropogenic activities, related to the extensive use of fossil fuels for energy purposes, have largely contributed to global climate change. Climate change occurs because of fossil fuel combustion resulting in elevated carbon dioxide (CO_2) concentrations in the atmosphere. CO_2 is a greenhouse gas (GHG) and as such increased CO_2 emissions and concentrations increase average global

[7] See, e.g. https://www.euractiv.com/section/energy-environment/linksdossier/eu-renewable-energy-policy/, https://www.euractiv.com/sections/energy/

[8] Available at www.mentalmodeler.org

[9] The known fossil fuel reserves however exceed the CO2 budget to remain below 2°C of warming according to the Paris Agreement. Hence, the finite character of fossil fuels is less relevant than it used to be under the Peak Oil theory era.

temperatures, along with many other effects (Mackay 2009). The concentration of atmospheric GHGs is now dangerously high.

Scientists and policymakers have long recognized the need for policies to effectively tackle this major environmental issue (Fox-Penner 2010). The Kyoto Protocol was adopted in 1997 and entered into force in 2005, an international treaty extending the 1992 United Nations Framework Convention on climate change (UNFCCC) and committing developed State Parties to reduce GHG emissions, based on the premise that (a) global warming exists and (b) it is caused by anthropogenic CO_2 emissions. The Kyoto Protocol's first commitment period started in 2008 and ended in 2012. Known as the Doha Amendment to the Kyoto Protocol, a second commitment period, 2013-2020, was adopted on in 2012, and as of 21 February 2019 ratified by 126 parties[10] .

2.2 European de-carbonization of the power sector

Early EU energy policies

The development of EU climate policy is closely related to the international negotiations of the United Nations (UN). It was in 1990, against the backdrop of the first summary report of the Intergovernmental Panel on Climate Change (IPCC) and in preparation of the upcoming negotiations on the UNFCCC, that climate change was discussed by the European Council for the first time. In the same year, EU leaders agreed to implement the first European climate target: stabilizing GHG emissions of the European Community at 1990 levels by 2000.

EC commitment after the Kyoto Protocol

In 1996, the European Community established its long-term goal of keeping global temperature rise below 2°C compared to pre-industrial levels. At the climate summit in Kyoto in December 1997, industrialized countries agreed on a set of quantitative GHG emission targets, with the European Community committing to an 8% emissions reduction of a basket of six GHGs during the commitment period 2008-2012 (compared to 1990 levels). Following the commitments made in Kyoto, an EU internal arrangement was agreed in 1998, which laid down the specific individual targets for the commitment period 2008-2012 for each of the 15 Member States (MS) to reach the overall reduction of 8%.

The 2020 “Climate and Energy” Package

In October 2005, the European Council gathered at the Informal Summit in Hampton Court, concerned by the pressing need to address the climate change challenge and to react to oil prices increase which approached $70 per barrel. These developments brought the European Council’s first request to the Commission for the development of a long-term and coherent energy policy on the issue of climate change.

The first step in this process was the Commission's Green Paper which spelled out options to achieve "sustainable, competitive and secure" energy supplies in the EU (EURACTIV 9/03/06). In September 2007, to complete the integration of the EU gas and electricity market, the Commission proposed further energy market liberalization measures, the so-called 'third package.'

Undoubtedly, the most important step towards a common EU energy policy to tackle climate change was taken with the EU Treaty of Lisbon of 2007 which laid down three key central goals for energy policy:

[10] https://unfccc.int/process/the-kyoto-protocol/the-doha-amendment

sustainability, competitiveness, and security of supply. More specifically, the common EU energy policy evolved around the objective of ensuring the uninterrupted physical availability of energy products and services on the market, at a price affordable for all consumers, while contributing to the EU's wider social and climate goals.

Although the EU has legislated in the area of energy policy for many years, the concept of introducing a rigorous and comprehensive energy policy to meet international climate change mitigation goals was only agreed in 2007, with the introduction of the so-called "20-20-20" targets for the year 2020. These targets included a reduction in GHG emissions of 20% compared to 1990 levels, an increase of renewable energy supply by at least 20% of total demand and an increase of energy efficiency by at least 20% compared with the business-as-usual scenario. To implement these targets, the EU Climate and Energy Package, a set of binding legislation was adopted in April 2009, following the political agreement between Council and Parliament in December 2008.

The SET-Plan

The Strategic Energy Technology (SET) Plan, agreed in March 2008, introduced priorities for future energy technologies. The objective of the SET plan was to lower the cost and improve the performance of low-carbon technologies and accelerate their market uptake to meet the 2020 energy policy objectives. The first SET Plan of 2008 was revised in 2015 to effectively line up with the EU's energy research and innovation priorities. The new integrated 2015 SET Plan was designed to accelerate the transformation of the EU's energy system and to bring promising new zero-emissions energy technologies to the market. Six broad categories of energy technologies have been identified:

- A set of 5 renewable technologies: off-shore wind energy, the next generation of solar PV, ocean energy, concentrated solar power (CSP) and deep geothermal energy
- Consumers in the energy system
- Efficient energy systems for buildings and industry
- Sustainable transport
- Carbon capture utilization and storage
- Safe nuclear power plants

Energy Roadmap 2050

In response to global environmental challenges, the EU has set itself a long-term goal of reducing GHG emissions by 80-95% (compared to 1990 levels) by 2050. Consequently, the EC has called for a European power sector that "can almost totally eliminate CO_2 emissions by 2050" (EC 2011). Towards this direction, the Energy Roadmap 2050 explores the transition of the energy system, establishing three key energy policy objectives: sustainability, competitiveness, and security of supply. The vision for the year 2050 identifies four main pathways for achieving these key objectives: energy efficiency, renewable energy, nuclear energy, and carbon capture and storage. It combines these routes in different ways to create and analyze seven possible scenarios for 2050. One of the decarbonization scenarios forecasts high renewable energy sources (RES) penetration. In this scenario, strong support measures for RES will lead to a very high share of RES in gross final energy consumption (75% in 2050) and a share of RES in electricity consumption reaching 97%. Overall, the Roadmap 2050 is not meant to replace national, regional and local efforts to modernize energy supply, but seeks to develop a long-term European technology-neutral framework in which these policies will be more effective in terms of security, solidarity, and costs.

The 2030 "Clean Energy for all Europeans" Package

In response to the consultation on the Green Paper, the EC proposed a new EU framework on climate and energy for 2030 on 22 January 2014. Based on EC conclusions of October 2014, on the 30th of November 2016 EC presented a new package of measures to keep the EU competitive, while achieving the transition to a low-carbon economy with the final consumer at its core, entitled "Clean Energy for All Europeans – unlocking Europe's growth potential." Essentially, the new package's objectives are underpinned by specific energy targets which must be met by 2030. These targets include a reduction in GHG emissions of 40% compared to 1990 levels, an increase of renewable energy supply by at least 27% of total demand and an increase of energy efficiency by at least 27% compared with the business-as-usual scenario. Additionally, the EC aims to support the completion of the internal energy market by achieving the existing electricity interconnection target of 10% by 2020, with a view to reaching 15% by 2030.

This transition towards a low-carbon energy system requires the transformation of passive consumers into ones that will participate actively in the production and use of energy, the so-called "prosumers" (Toffler 1980). The new energy package envisages active consumers who will be central players in the energy markets of the future. Consumers across the EU will in the future have a better choice of supply, access to reliable energy price comparison tools and the option of producing and selling their own electricity.

2.3 EU Electricity Directives

For a long time (the era before 1996), the electricity sector in the EU member states was organized in the form of a natural vertically integrated state-owned monopoly. In Europe, the liberalization and restructuring of the electricity markets is part of the trend toward liberalization and the withdrawal of the state from involvement in infrastructure industries and involves three different electricity directives.

First Electricity Directive (96/92/EC)

In Europe, the liberalization and restructuring of the electricity markets started mainly with the introduction of the EU's first Electricity Directive on February 19, 1996 (Meletiou et al. 2018). This involved accounting unbundling, which refers to the requirement of electricity undertakings to keep separate internal accounts for each of their transmission and distribution activities. Additionally, the first Electricity Directive contains provisions ensuring that large users were able to choose their suppliers freely.

Second Electricity Directive (2003/54/EC)

The second Electricity Directive further promoted market competition by stronger network access regulation and by requiring the establishment of an independent regulatory body together with environmental protection and promotion of renewable resources in line with the protection of consumers' fundamental interests (Jakovac, 2012). For competition to work, access to networks should be non-discriminatory, transparent and under fair prices. Thus, going beyond the provisions of the first directive, the second introduced a reinforced unbundling regime, the legal unbundling, where transmission system operators (TSOs) had to be operated through separate legal entities when they were part of a vertically integrated undertaking (VIU).

Third Electricity Directive and Electricity Regulation (Directive 2009/72/EC)

In its sector inquiry of 2007, the EC argued that the development of competition in European energy markets was too slow (EC 2007a) and for this reason put the issue of ownership unbundling at the centre of the third Electricity Directive. (Brunekreeft 2015; Heddenhausen 2007). In principle, the Third Directive allows utilities to choose among three alternative unbundling regimes: a) ownership unbundling (OU), b) independent transmission operator (ITO), or c) independent system operator (ISO).

Fourth Electricity Directive and Regulation (part of Clean Energy for All Europeans package)

On 30 November 2016 the EC presented the Clean Energy for all Europeans package. The package includes a proposal for both a revised electricity Directive and regulation of the internal market for electricity.

2.4 EU Energy-related global and European de-carbonization of the power sector

The EU energy-related Directives promote energy efficiency and renewable energy use in electricity generation. These directives, among others, help the EU to achieve lower GHG emissions, and to decarbonize its power sector.

RES Directive (2001/77/EC)

The first Renewable Energy Sources (RES) Directive was published in September 2001, the "Directive on the promotion of electricity produced from RES in the internal electricity market." It follows the 1997 White Paper on RES which set a target of 12% of gross inland energy consumption from renewables for the EU-15 by 2010, of which electricity would represent 22.1%. The Directive determined indicative national targets to encourage EU Member States (MS) to increase the share of electricity produced from RES. In 2012 it was repealed by the RES Directive 2009/28/EC.

Biofuel Directive (2003/30/EC)

In May 2003 the directive on "the promotion of the use of biofuels or other renewable fuels for transport," known as the first Biofuel Directive, was published. It recognized that the transport sector accounted for more than 30% of energy consumption, with an increasing tendency. It highlights the significant potential to produce biofuels from a wide range of biomass such as agricultural and forestry products, industrial residues and waste. This Directive promotes the use of biofuels or other renewable fuels to replace diesel and petrol used in the transport sector. The MS must ensure that such fuels take national market shares through indicative national targets. Targets include reference values of the energy content provided by biofuels or other renewable fuel in petrol/diesel used for transport purposes: 2% by 31 December 2005 and 5.75% by 31 December 2010.

RES Directive (2009/28/EC)

The 2009 RES Directive establishes an overall EU policy for the production and promotion of RES. The directive defines these as non-fossil sources, namely wind, solar, geothermal, ocean energy, hydropower, biomass, and renewable biogases. It requires the EU to meet at least 20% of its total energy needs with renewables by 2020. This is to be achieved through mandatory national targets which reflect MS' different starting points for renewables production and ability to further increase it – from 10% in Malta to 49% in Sweden. In order to reach their targets, the MS must promote energy efficiency measures and encourage RES deployment by designing effective supporting schemes. Additionally, all MS must ensure that at least

10% of their transport fuels come from renewable sources by 2020. This target, contrary to the energy one, is the same for all MS to ensure consistency in the specifications and availability.

RED II

On November 30, 2016, the EC published a formal proposal to the EU Council and the European Parliament to recast RES Directive 2009/28/EC, which will expire at the end of 2020. The proposed new directive, also known as RED II, will be a part of EC's 'Clean Energy for all Europeans' package and will enter into effect on January 1, 2021, covering the period 2021 – 2030. RED II proposes a set of policy measures to achieve a 32% share of energy from renewable sources in the Union's gross final consumption of energy by 2030. The agreement also foresees an upward review clause by 2023, at the latest. Accordingly, a target for renewable energy in transport is expected to be set at 14% by 2030 reflecting the intention towards increased use of electric vehicles. The agreement also foresees a 3.5% target for second-generation biofuels (i.e., fuels produced from sources other than food crops). Member States must transpose RED II provisions into national legislation by 30 June, 2021 with several technicalities and revision clauses being defined via delegated and implementing acts.

Important aspects of the agreement include plans to:

- Improve the design and stability of support schemes for RES
- Reduce the administrative procedures related to RES
- Establish a clear and stable regulatory framework for self-consumption
- Increase ambition in the transport and heating/cooling sectors

Energy Efficiency Directives (EED 2012/27/EU)

The 2012 Energy Efficiency Directive (EED 2012/27/EU) established a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. Under the Directive, all EU MS were required to use energy more efficiently at all stages of the energy chain, from production to final consumption. The EED 2012/27/EU repealed the Cogeneration Directive (2004/8/EC) and the Energy End-Use Efficiency and Energy Services Directive (2006/32/EC).

The Energy Efficiency Directive put a major focus on targets. The first target concerns the indicative 20% target mentioned above. The target calls for energy consumption for the entire EU of no more than 1 474 Mtoe of primary energy and/or no more than 1 078 Mtoe of final energy in 2020. The second target concerns the public sector, requesting each MS to ensure that, as from 1 January 2014, 3% of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year." The third target concerns specific energy savings from an energy efficiency obligation. According to Article 7: "That target shall be at least equivalent to achieving new savings each year from 1 January 2014 to 31 December 2020 of 1,5% of the annual energy sales to final customers of all energy distributors or all retail energy sales companies by volume, averaged over the most recent three-year period prior to 1 January 2013."

New Energy Efficiency Directive

On 30 November 2016, the EC proposed a revised Energy Efficiency Directive, including a new 30% energy efficiency target for 2030, including measures to assure that the new target is met:

- Energy distributors or retailers must achieve 1.5% energy savings per year through the implementation of energy efficiency measures.
- EU MS can opt to achieve the same level of savings through other means, such as improving the efficiency of heating systems, installing double glazed windows or insulating roofs.
- The public sector in EU MS should purchase energy efficient buildings, products, and services.
- Every year, EU MS governments must carry out energy efficient renovations on at least 3% (by floor area) of the buildings they own and occupy.
- Energy consumers should be empowered to manage consumption better. This includes ease of access to data on consumption through individual metering.

Following the political agreement for the RED II, a consensus was also reached for the 2030 energy efficiency target. Accordingly, on June 19, 2018, the Commission, the European Parliament, and the Council agreed on a 32.5% target with an upwards revision clause by 2023. The target is expected to support energy savings in the next period 2021-2030 and beyond, coming from new energy efficiency renovations and other measures. This political agreement was finally approved by the European Parliament and the Council. Subsequently, the updated Energy Efficiency Directive will be published in the Official Journal of the Union and will enter into force 20 days after its publication.

Water Framework Directive (2000/60/EC)

The 2003 Water Framework Directive (WFD; Directive 2000/60/EC) is not directly related to energy production but affects the sector and particularly the development of new hydropower. It aims to prevent the deterioration of EU waters and for them to achieve “good status” by 2015. As such, new hydro construction projects must avoid damaging water bodies while existing projects must mitigate their impacts (e.g., construction of fish passages).

3. Key Energy Technologies

Taking into consideration the technologies identified through the two SET-Plans as well as the share of the contribution of energy technologies in the European energy mix, the following key energy technologies can be identified:

3.1 Solar energy

3.1.1 Description of the technology

Solar energy harnesses the power of the sun to generate electricity either directly through photovoltaic (PV) cells or indirectly using concentrated solar power (CSP). CSP technologies produce electricity by concentrating solar radiation to heat a medium (usually liquid or gas) used in a heat engine process (steam or gas turbine) to drive an electrical generator. PV is the most widespread solar technology for electricity generation, using semiconductor devices known as solar cells which can be connected to form a solar panel. Some solar PV sub-technologies are commercially available, including technologies such as crystalline silicon (c-Si, approximately 95% of total installations) and thin-film technologies (CdTe). Others are still developing and have not reached market maturity.

Solar PV systems are scalable: they range from rooftop systems with a power capacity of a few kilowatt power (kWp) to large-scale solar energy generation, usually referred to as Utility-Scale Solar Energy (USSE) in the form of multi-megawatt solar stations (i.e., capacity 20 megawatt (MW) and above). Accordingly, there are two main PV market segments: ground-mounted and rooftop solar PV power systems. Ground-mounted systems are USSE systems feeding into the central electricity grid. Rooftop PV systems are installed on commercial or residential buildings, and part of the electricity produced is consumed at the source with the rest fed into the grid. The global installed power capacity of PV was approximately 402.5 gigawatt power (GWp) at the end of 2017, with EU installations accounting for 108 GWp. During 2017, 97 GWp of new solar PV systems were installed globally, to which EU installations contributed 5.2 GWp (Jäger-Waldau 2018). Investment analysts and the industry expect the next few years to show continued strong growth of solar PV.

3.1.2 Biodiversity impact of utility-scale PV

The biodiversity impact of solar PV systems is generally low. However, USSE systems can affect ecosystems in multiple ways throughout their lifecycle (construction–operation–decommission) (Lovich and Ennen 2011), and their impact can be categorised as:

- Land use competition
- Habitat loss/change
- Visual impact
- GHG emissions
- Natural resources
- Hazardous material and chemical pollution

Larger utility-scale photovoltaic electricity generation plants raise concerns about land use competition, land degradation, and habitat loss. Depending on the technology, site topography and location, estimates indicate that the generation of utility-scale PV systems requires 12,000 m^2 to 40,000 m^2 per MW (Fylladitakis 2018). Supporting infrastructure (e.g., access roads and electrical equipment) and the spacing requirement of the panels can result in the actual space requirement of solar power installations being around 2.5 times the area of the panels themselves (Turney and Fthenakis 2011).

Land use competition is generally considered an important challenge of solar energy facilities which require relatively large areas for solar radiation collection when used to generate electricity at utility-scale (Gasparatos et al. 2017). Since a large area of land is occupied, this may displace some of the traditional uses of the land like greenfield and agricultural (loss of cultivable land) or even prevent the land from being maintained as areas of wildlife, fauna, and flora[11]. The practice of large-scale systems occupying greenfield,

[11] In very specific cases, construction of a large scale solar farms may allow for change of use from agricultural to management for wildlife.

agricultural areas was supported by certain distortions in the energy market, mainly due to the financial incentives of solar PV systems in their early phase of development. More recently, both researchers and policy makers have supported alternative pathways. The utilization of the building stock potential with a wide installation of rooftop systems is considered a good strategy that also creates multiple synergies (e.g., the combination with building renovation works and implementation of the Energy Efficiency Directive). The use of brownfield[12] areas such as closed landfills, contaminated land, old mines is also an approach that attracts increased attention.

The process of preparation of the land for the construction of solar facilities requires clearing and removal of upper soil layers (Gasparatos et al. 2017). The clearing and use of large areas of land for solar power facilities can seriously affect local flora and fauna leading to loss of habitat of local wildlife. Regarding habitat change, USSE infrastructure can fragment habitats, become a barrier to the movement of species, affect hiding places, preying strategies and the availability of food (Hernandez et al. 2014, Turney and Fthenakis 2011). However, research on the actual impact of solar panels on animal behavior over a long period of exposure to the panels has not yet been reported (Prakash et al. 2015).

The visual impact of solar systems has also been highlighted in studies (Fabrizio and Garnero 2012). The visual intrusion of a solar system depends on its scale, type and location. A large-scale system in the vicinity of an area of high natural and ecological importance will have negative effects. This is the case for most types of construction, and therefore priority needs to be given to other locations. Some recent designs for solar PV systems ensure harmonious integration into natural or urban environments. New solar sub-technologies and design methods also enable more flexible design of solar PV installations. The most well-known action is probably the annual forum of the European Photovoltaic Solar Energy Conference and the exhibition titled "Photovoltaics, Forms, Landscapes."

GHG emissions of solar PV systems are exclusively related to the construction phase, as their operation includes no emissions at all. In terms of life cycle assessment (LCA), i.e., the assessment of the production of emissions throughout the system's production, use, and disposal, the impacts of solar PV depends on the energy efficiency of the manufacturing system (Tsoutsos et al. 2005). According to recent analyses (Nugent and Sovacool 2014), solar PV emits on average 49.9g of CO_2/kWh on an LCA basis. Solar PV module production is an energy-intensive process. Technological breakthroughs (e.g., thinner cell layers) have allowed the continuous reduction of the required energy and the associated GHG emissions. However, emissions also depend on how the modules are transported, the construction-installation phase, and the operation and maintenance (O&M) phase.

The production of photovoltaic panels also requires very large quantities of bulk materials, including common minerals such as iron, copper, and aluminum. Even though these materials are recyclable, the immense mineral depletion numbers should not be ignored. Studies report that 3.3 g of iron ore and 1.2 g of aluminum ore (bauxite) are necessary per produced kWh (Pehnt 2006). Finally, the manufacturing of PV modules may involve the use of scarce materials such as telluride, indium, cadmium, and gallium, even though the quantities required are small.

PV manufacture may involve hazardous materials, and their release into the environment is frequently considered the most critical negative environmental impact of both large and small PV systems (Tsoutsos et al. 2005). The used raw materials include aluminium (Al), arsenic (As), cadmium (Cd), cadmium telluride (CdTe), hexavalent chromium (CrVI), copper (Cu), gallium (Ga), indium (In), lead (Pb) and some

[12] See for example solar developments in the UK on the brownfield site of Rampisham.

intermediate products ($SiCl_4$, $SiHCl_3$), must be carefully considered and managed. For instance, mining and refining quartz, the most common material used in crystalline silicon panels, can pose significant environmental risks through the release of crystalline silica dust. This can cause silicosis, a lung disease where scar tissue forms in the lungs and reduces the ability to breathe (Prakash et al. 2015). Cleaning and purification of the semiconductor surface of photovoltaic cells is the manufacturing process involving the greatest use of hazardous materials. Common hazardous materials associated with this process include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, trichloroethane, and acetone. However, the amount and type of chemicals used depends on the type of cell, and the size of the silicon wafer (Hand et al. 2012). More advanced technologies also tend to require a wider range of hazardous materials for their manufacture.

Despite the promise of solar power as a cleaner source of long-term electricity generation, it is not without its problems regarding the environmental standards of minerals and raw material sourcing. Almost all of the materials used in PV manufacturing are currently mined and processed outside the EU (mainly in Asia and Africa), in particular in areas with relatively lax environmental standards. Recently, solar PV manufacturers have come under increasing pressure to disclose whether materials in their supply chain are sourced from mines in conflict zones (PVTECH 2015). Along these lines, EU legislation[13] aims at encouraging companies to alter their business models and ensure raw materials are sourced and produced to the highest possible standard.

3.2 Wind energy

3.2.1 Description of the technology

Wind energy has been utilized for centuries, but it was only in the 1980s that the technology reached sufficient maturity for large-scale electricity production. The power capacity of onshore wind turbines ranges from 2-4 MW with rotor diameters 97-130m. Offshore projects commonly employ larger capacities between 3-8 MW (rotor diameter 112-164 m). Currently, Vestas V164 is the wind turbine with the largest nameplate power capacity. It was originally designed for 8 MW and upgraded at 9.5 MW, retaining a rotor diameter of 164m. Generally, there are no significant differences, in terms of design and components, between wind turbines aimed at onshore and offshore applications.

Wind turbines capture energy at wind speeds of 3-5 m/s, with the electricity production increasing initially about the cubed wind speed. At wind speed levels of approximately 12 m/s and beyond, the output remains constant. In particularly strong winds, the turbine rotors must either be slowed down or turned off to avoid risking their mechanical stability. Naturally, the exact values depend on the design characteristics of the wind turbine.

According to the World Wind Energy Association, the worldwide capacity of wind turbines was 539 291 MW at the end of 2017. It is estimated that 52,552 MW were added in 2017, a slight increase from the 51,402 MW in 2016. The installed capacities can cover more than 5% of global electricity needs. The EU hosted 149,217 MW of wind energy at the end of 2016 with a total installed capacity of 153.7 GW. According to WindEurope's Central Scenario, 323 GW of cumulative wind energy capacity is expected to be installed in the EU by 2030, 253 GW onshore and 70 GW offshore (Wind Europe 2017).

[13] http://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/

3.2.2 Biodiversity impact of wind energy

While wind energy generation can have a number of ecological impacts on avian species, the affected species, mechanisms and magnitude of these ecological impacts depend to a large extent on whether it is generated onshore or offshore (Gasparatos et al. 2017). The biodiversity impacts of wind energy include:

- Noise pollution
- Visual impacts
- Wildlife loss (birds and bats)
- Habitat loss
- GHG emissions
- Depletion of natural resources

Noise pollution is often regarded as the most critical environmental impact of wind energy (Saidur et al. 2011). It affects the wildlife and the health-wellbeing of people living in the vicinity of a wind farm and can also negatively impact land value. Wind energy noise is divided into mechanical and aerodynamic. Mechanical noise is the result of the moving parts and can be reduced by regular maintenance. Aerodynamic noise has been the focus of extensive industrial research and development (R&D), as it can be significantly mitigated by advanced blade design approaches.

A visual impact assessment has been carried out (Ladenburg 2009) to evaluate the negative effect of a wind turbine. It was shown that the impact varies according to the turbine characteristics including the size, color-contrast, distance from inhabited areas, and the role of shadow flickering. Timing has also appeared to be important because analyses revealed that the visual impact is bigger in operation mode than in stationary condition (Jaskelevičius and Užpelkiene 2008.). The visual impact of wind farms is probably the main driver of negative perceptions of wind energy. This has also raised discussions of environmental justice (Cowell et al. 2011) in relation to community benefits to support public acceptance and counter-balance the negative visual impact of wind energy. Offshore wind farms can be an attractive alternative as they are located near to population hubs and yet far enough away to mitigate community opposition (Chu and Majumdar 2012).

Wind energy is generally considered compatible with wildlife and birds. Some wildlife impacts can be categorized into direct and indirect. Direct impacts relate to birds' mortality from collisions with the blades, while indirect impacts refer to habitat disruption and noise (discussed below in the context of habitat loss). Early analyses claim that these impacts are smaller than those of other energy sources (Magoha 2002). In general, bird species that are rare/endangered, or have long lifespans and are slow to reproduce, face the greatest risk from the deployment of wind turbines (Carrete et al. 2009, Schaub 2012; Furness et al. 2013). Greater collision risks exist around heavily used flyways (including migratory routes) or in areas that are regularly used for feeding and/or roosting (Tabassum et al. 2014). Regional and overall analysis of birds' fatality rates in the United States shows an average number of 2.3 deaths per turbine per year (Saidur et al. 2011). However, according to another study by Loss et al. (2013), wind turbines in the United States alone kill an estimated 234,000 birds annually. Bats suffer disproportionately more than birds (Bastian 2013; Pearce-Higgins et al. 2012), with the impact estimated to be to the order of tens of bat fatalities per turbine per year. Researchers and industrial R&D based on the available evidence aim at finding optimal positions of wind farms to minimize bird mortality. Additional measures include the use of avian radars that detect birds in the area and stop the wind turbines in cases of high risk to birds. More important is a good understanding of the breeding and feeding behaviours of local wildlife, which depends on research carried out before wind farm construction.

Wind turbines require a large land area for siting, construction, and operation. Regarding habitat loss, it has been reported that different bird and bat species might avoid areas that contain wind generators (Gasparatos et al. 2017). However, several studies have found minimal effects of wind farms on the occurrence/sightings of several species, including wintering birds in farmlands (Devereux et al. 2008), or birds in cropland and secondary forests in southern Mexico (Villegas-Patraca et al. 2012). Environmental Impact Assessments (EIAs) and post-construction monitoring studies have found no discernible effects on the populations of black grouse.

For large-scale wind farms, there are some concerns about potential changes in the local climate. However, in most cases, these lack scientific foundations and are published in local newspapers and periodicals without supporting evidence (Leung and Yang, 2012). This knowledge gap has been partially covered by some studies which simulated wind turbines' climatic impact by changing the drag coefficients of the surface in two different general circulation models. Findings have shown that the effect of wind power on the global average surface temperature is only minor.

The majority of the energy costs in a wind turbine’s life cycle are produced in the obtaining of raw materials and the manufacturing of the wind turbine components due to the amount of fossil fuel-based manufacturing plants. In terms of GHG emission using an LCA, wind energy emits 0.4 g CO_2-eq/kWh to 364.8 g, with a mean value equal to 34.11 g CO_2-eq/kWh. These values are approximately 30% lower than that for solar PV. A 2007 compilation of onshore wind turbine data by the European Wind Energy Association suggested that the overall environmental footprint for wind-generated electricity is relatively small when compared with other sources of energy (European Wind Energy Association 2007). Turbines represent about 60% of the total emissions, while construction and operation are responsible for an additional 20% each (Nugent and Sovacool 2014).

Concerning the depletion of natural resources, the wind energy manufacturing process does not require the use of vast quantities of raw materials or rare materials. A typical wind turbine is reported to contain 89.1 percent steel, 5.8 percent fiberglass, 1.6 percent copper, 1.3 percent concrete (primarily cement, water, aggregates, and steel reinforcement), 1.1 percent adhesives, 0.8 percent aluminium, and 0.4 percent core materials (primarily foam, plastic, and wood) by weight (U.S. Department of Energy 2008). The results of a recent study (U.S. Department of Energy 2008) suggest that there should not be a shortage of the principal materials required for electricity generation from wind energy for the achievement of the market goal of 20% by 2030 for the US.

3.3 Marine energy sources: tidal and ocean

3.3.1 Description of the technology

Marine potential energy occurs in waves, tidal ranges, tidal currents, ocean currents as well as temperature differences and salinity gradients (Lewis et al. 2011). It is mainly utilised through tidal current energy systems; these vary, with the most common types of turbine designs being a) tidal turbines, b) tidal lagoons and c) tidal barrages.

At the moment 233 MW of marine energy is installed and connected to the EU central grids, mainly in France and the UK (Eurostat 2016). Despite the increased interest as demonstrated by EC initiatives, marine energy is developing slowly and has a limited market (Magagna and Uihlein 2015). In Europe, MS targets set out in the 2009 National Renewable Energy Action Plans (NREAPs) expect wave and tidal energy capacity to reach 2250 MW, about 0.5% of the total installed electricity capacity in the EU, by 2020. The EU target is for 1.9 GW by 2020. However, current forecasts estimate a global installed capacity of only about 170 MW by 2020, which represents only 7% of the NREAP targets (Bloomberg 2014). By 2050, Europe aims to have up to 100GW of wave and tidal energy installed capacity delivering 260 terawatt hours (TWh) of clean, affordable and reliable electricity (OEE 2013).

Tidal turbines

Tidal or marine current turbines operate in a manner very similar to a wind turbine and can generate electrical power from strong horizontal tidal currents. Tidal turbines are placed on the ocean floor and operate just below the sea surface with the stream currents flowing across the turbine blades to power a generator. Tidal stream generator is a rather new technology with the first "big-size" project, the "SeaGen", taking place in 2007, including a 1.2 MW turbine installation in Northern Ireland. Several efforts have been made to install major tidal projects, but they are still considered to be at the pre-commercial, demonstration phase, as indicated by the relatively low capacity factor achieved so far, i.e., average power generated divided by peak power, currently in the range of 25-30%.

Tidal Lagoon

A tidal lagoon is a power station that generates electricity from the natural rise and fall of the tides. Tidal lagoons work in a similar way to tidal barrages by capturing a large volume of water behind a human-made structure which is then released to drive turbines and generate electricity. Unlike a barrage, where the structure spans an entire river estuary in a straight line, a tidal lagoon encloses an area of coastline with a high tidal range behind a breakwater, with a footprint carefully designed for the local environment.

Tidal Barrage

Tidal barrage systems use the potential energy from the difference in height between high and low tides by capturing the waters brought in by high tides in a holding area (similar to a hydro dam) before releasing them through a generator once the tide has receded (Boronowski et al. 2008). In Europe, La Rance tidal power plant on the estuary of the Rance River in Brittany, France, has been operational since 1966 making it the world's oldest and second biggest tidal power station, with an installed capacity of 240 MW. With similar capacity, the Swansea Bay Tidal Lagoon project will be built at Swansea Bay in the UK, to become the world's third-biggest tidal power project upon completion.

3.3.2 Biodiversity impact of marine energy

The environmental impacts of tidal energy sources depend on the technology as well as on the geographical location of the installation. Additionally, different impacts may be considered during the construction, the operation, and the decommissioning phase. Tidal energy may present the following impacts:

- Wildlife loss
- Erosion and morphological and sediment quality
- Plankton disturbance
- Depletion of natural resources

The deeper diving species of birds are more likely to encounter tidal turbine devices, thus running a collision risk (Furness et al., 2012; Waggitt & Scott, 2014). Research to date suggests that blade strikes do not affect marine life: according to most observations, marine animals avoid the turbines altogether, and in the few cases when fish were noted to pass through the turbine-swept area, survival rates were 98% or higher (Magagna and Uihlein 2015). In situ studies also indicate that larger marine life generally avoids hydrokinetic turbines (Keenan et al. 2011). However, areas with high tidal current flows are not the most suitable habitat for spawning or nursery grounds for fish or shellfish (SDC 2007). Additionally, marine animals, such as fish and mammals, can also be influenced by the electromagnetic fields of tidal energy devices due to the fact that they rely on earth's magnetic field to navigate (Gill 2005).

A tidal lagoon could cause undesired consequences to birds and marine mammals (such as grey seals) during both construction and operation and decommissioning phase (Tidal Lagoon Power 2019). This can happen through a number of pathways including the risk of collision, increased noise, the barrier to movement, changes in water quality and changes to foraging habitat or food resource as an indirect impact from alterations in coastal processes. Concerning fish, a lagoon presents primarily physical disturbances such as disrupting and altering migration routes (SDC 2007). Furthermore, the electromagnetic field produced will affect biodiversity and might cause habitat loss (SDC 2007).

The effect of tidal barrages on wildlife is associated with habitat loss/change and concerns species entrapment rather than collision. Tidal barrages can cause the permanent inundation of the upstream portion of estuaries (Kidd et al. 2015). Habitat change from ocean energy installations can be a more substantial driver of ecosystem change and biodiversity loss, for example, whale entrapment at the Annapolis tidal barrage in Canada.

Intertidal erosion is another environmental risk that occurs from tidal stream generator devices. Since arrays impact the velocity and turbulence of flow, their installation may cause soil and sediment transport and erosion processes which may impact on the landscape as well as the seascape (SDC, 2007). Some surveys, such as that carried out by the Sustainable Development Commission (2007), note seabed alteration as a result of the installation of the devices and the cabling arrangements. Intertidal erosion may be caused by the construction of an artificial lagoon. It can also induce changes in the community of the benthic fauna which dominates in sandy sediments. These areas are characterized by intensive storms and variable tidal regimes, which, in combination with sedimentary processes, could disturb intertidal habitats and likely inshore fisheries (SDC 2007).

Finally, similar to conventional hydroelectric dams, tidal barrages can change sediment loading, salinity, and water turbidity or influence the exchange between flushing of oxygenated water (Copping et al. 2013). This can lead to instances of mass mortality of fish and other benthic species (Broadhurst et al. 2014).

Plankton is a vital food source for fish, and the level of tidal flows and tidal mix influences its growth. Consequently, tidal turbine installation may lead to changes in the plankton community and affect plankton productivity. Tidal lagoon technology may cause severe consequences for plankton. In the construction phase, there may be a high risk of accumulation of contaminants. However, the most significant risk occurs in the operation phase, where there may be adverse changes in sedimentation and reduced turbidity in the water. This will reduce water nutrients, leading to lower plankton productivity (SDC 2007). Tidal barrages may lead to harmful algae blooms and changes in the plankton communities (especially when installations concern estuary areas) (SDC 2007b).

Tidal barrages are essentially dams stretching across the full width of a tidal estuary. The construction of a tidal barrage requires a vast quantity of raw materials, mainly concrete and steel, to withstand the huge loads produced from dammed water. The same specifics are likely to apply to tidal lagoon schemes, although these are likely to be smaller constructions requiring less raw material and shorter construction periods.

Tidal stream devices are faster to build than tidal range schemes, require fewer raw materials, and have a shorter period before the commencement of electricity generation.

3.4 Hydropower

3.4.1 Description of the technology

Hydropower technology is relatively advanced, having provided electricity for more than a century. This distinguishes it from some modern renewable energy sources (RES), especially those still to reach market maturity (e.g., ocean energy). Apart from energy production, hydroelectric facilities also provide other services, e.g., reservoirs use dam water for irrigation, drinking water provision, flood control, etc. This multi-purpose character creates interactions and allows synergies, but also challenges and trade-offs that require an integrated approach. There are different types of hydropower stations. Conventional large-scale hydropower refers to reservoir hydroelectric facilities that store massive amounts of water behind a dam. Run-of-river hydropower utilizes the flow of water courses, typically rivers, without large dams (a weir is often sufficient). Hydropower stations range from the very small (pico) scale with a nominal power capacity of a few kW to projects of huge scale, e.g., the Three Gorges Dam in the Yangtze River with a world-leading capacity of 22,500 MW.

Reservoir hydropower is the most flexible bulk electricity production technology, as its output can vary according to the demand in the power system. In addition, pumped hydropower storage (PHS) is the main bulk electricity storage technology representing ≈99% of current storage capacities. Hydropower is widely used for electricity production at the global scale, partly due to its ability to provide low-cost electricity. Each station is unique in terms of design, and it is often necessary to develop tailor-made solutions for hydropower components and civil works. Presently, approximately 160 countries use hydropower for energy production with more than 1270 GW of global hydro capacity (Whiteman et al. 2018). At the end of 2016, 106,062 MW of hydropower was installed in the EU along with an additional 47,907 MW of PHS.

3.4.2 Biodiversity impact of Hydropower

Hydropower and particularly large-scale reservoir systems involve environmental, social and economic impacts as their massive scale leads to a radical transformation of landscapes. In the EU, a large proportion of the available technical hydropower potential has already been tapped, including the most advantageous locations. As far as hydropower is concerned, it is a challenge to simultaneously pursue RES deployment (according to the Renewable Energy Directive) and the environmental goals described in the Water Framework Directive (WFD). This explains the very slow growth of hydropower over the past decade, with the majority of the large-scale stations being PHS stations that have a lower environmental impact. Impacts of hydropower include:

- Habitat change, biodiversity impacts
- Water quality changes

- Economic impacts
- Social impacts

The environmental consequences of large-scale dam construction can be multiple and varied. The river upstream of the dam is transformed from a freely flowing river to an artificial lake, where releases are controlled, mainly based on energy needs. Downstream of the dam the changes in the flow regime may have serious consequences. Too small water releases do not allow for the ecological conservation of the river (environmental flow). Sudden, large water releases can result in flash flood events.

The transformation of a river to an artificial reservoir creates changes in the water depth, temperature, chemical composition, dissolved oxygen levels, among others. The new conditions may not be suitable for aquatic plants and wildlife (animals, birds). The dam itself does not allow fish migration, which is particularly important for some species. Technologies such as fish ladders and fish bypasses have been designed and extensively tested in real conditions to mitigate this. Fish-friendly turbines are also a relatively recent technological breakthrough, allowing fish to pass through the operating hydro turbines with very low mortality rates. The dam also traps sediments, which are important for maintaining the physical processes downstream of the dam (e.g., river deltas and wetlands). Changes in sediment loading and nutrient cycles can have negative environmental effects such as eutrophication which may result in a decline of water quality (upstream, downstream and within the reservoir), eventually leading to biodiversity loss (Gasparatos et al. 2017). However, there have been cases of hydropower plants (mainly small-scale) that had negligible effects on water quality (Pimenta et al. 2012), or whose initial negative effects were stabilized over time, eventually reaching the pre-plant water quality levels (Valero et al. 2012).

Hydropower has also been associated with an increase in GHG emissions. Although hydropower operation includes almost zero emissions, the construction of civil works includes emissions. Moreover, and particularly for dams constructed in tropical zones, there is scientific evidence that the emissions contribution of the submerged organic matter, following the filling of the reservoir, may be larger than expected (Gunkel, 2009; Fearnside 2015). Hydropower plants can emit large amounts of GHGs, mainly carbon dioxide and methane from reservoirs (Gasparatos et al. 2017). These emissions can be comparable to (or even exceed) those of conventional power plants (Gasparatos et al. 2017). However, some recent studies suggest lower overall GHG emissions than initially expected.

In terms of economic impact, hydropower is a capital-intensive technology with a major part of the investment required in the early stages of development. It is generally accepted that hydropower can provide electricity at very advantageous economic costs. However, deployment may require feasibility and environmental impact assessments, planning, design and civil engineering work that increase the construction times up to 7-9 years for conventional large-scale stations.

In terms of raw material, building a hydroelectric dam starts with a base which blocks the flow of water. The base is usually created by pouring tons of rock, sand, gravel, and dirt into the channel. The second material used in building a hydroelectric dam is concrete. Concrete is poured around the earthen base to provide shape, structure, and strength to the dam. Finally, steel plays a critical part in large-scale construction projects: reinforcing steel bars are inserted into the concrete to provide added dimensional strength.

The social impact of hydropower (Winemiller et al. 2016) includes forced relocation of human populations and expanding deforestation because of the need to construct new access roads. An additional issue may be a lack of transparency during dam approval processes. This has led to issues with affected populations appearing to be unaware of the wide range of potential detrimental social impacts.

3.5 Geothermal energy

3.5.1 Description of the technology

Geothermal energy for electricity production is an RES at commercial market maturity as the first power generation geothermal station started operation in 1905 (DeRippo 2016). In 1911, Lardarello in Tuscany, Italy became the first commercial power plant. Geothermal energy is based on thermal energy stored in the interior of the Earth. Hot steam is transferred to the surface by groundwater through boreholes. Geothermal fields are either low, medium- or high-enthalpy, depending on the temperature. High-enthalpy fields generally have temperatures exceeding 150-180°C and are found around tectonic plate boundaries where volcanic activity is high. These are best suited for electricity production. Medium- (150-180°C) and low-enthalpy (50-100°C) geothermal fields can be used to provide thermal energy for direct use; this use is much more widespread than electricity provision. Direct uses usually include heat pumps for district and space heating, productive agricultural uses (greenhouse heating, drying products), recreation (thermal baths, swimming) and others.

Geothermal power projects have specific risk factors compared to other RES such as resource risk. To assess and verify the existing potential in a given location, it is required to perform drilling tests that sufficiently increase the cost of the feasibility studies. The legal aspects of geothermal energy are also very important as the regulatory framework is demanding and complex, often delaying projects' realization.

At the end of 2017, the global total installed geothermal energy, including both electricity and thermal, exceeded 83 GW. Geothermal electricity production accounted for approximately 14 GW, concentrated in a small number of countries. At the end of 2016, the EU hosted 55 operating geothermal power plants with a cumulative power capacity of 824 MW (World Energy Council 2016). This is well below the trajectories predicted in terms of the EU National Renewable Energy Action Plans (NREAPs). With regard to NREAP targets, EU geothermal deployment represented approximately 51% of the 2020 electricity targets (1623 MW) and 26% of 2020 heating targets.

3.5.2 Biodiversity impact of geothermal energy

The environmental impact of using geothermal energy for electricity production has also been the subject of numerous studies and debates. Geothermal is a clean energy source and has low direct GHG emissions (Amponsha et al. 2014), considerably below those of most other technologies (Rybach 2003). Its deployment involves a series of processes and the installation of components such as boreholes, pipelines and cooling towers that have an environmental impact (Bayer et al. 2013). It may have a negative impact on the following areas (Di Pippo 1991):

- Habitat change/loss
- Surface disturbances
- Water (lowering groundwater table, thermal and chemical pollution)
- Physical effects (land settlement, landslides)
- Noise, visual and heat impacts

- Operational risks
- Social acceptance

Geothermal energy generation has been associated with habitat change and loss, often in highly biodiverse and/or fragile ecosystems. For example, in Kenya, the Olkaria geothermal power project is situated in the Hell's Gate National Park, and habitat loss has resulted from the geothermal facilities and ancillary infrastructure (Gasparatos et al. 2017).

Surface disturbances may occur during the drilling of the geothermal well but are generally removed once this is completed. Accordingly, the drill rigs are removed, the ponds are drained, and restoration may return the landscape to its former status (Kristmannsdóttir and Ármannsson 2003). Surface disturbance may also include road construction in cases where there is no access to the under-development power station.

Fluid withdrawal involves several risks and can lead to environmental impacts. Firstly, it may affect existing hot springs or transform them. This is the result of lowering the groundwater table especially if pumping exceeds the natural inflows for a long period. Lowering of the groundwater table may also change the geometry of the aquifers and lead in the mixing of fluids between different aquifers. The effects of fluid withdrawal can be overcome to a large extent if the withdrawn geothermal fluid is injected back (recycling) into the aquifer (Kristmannsdóttir and Ármannsson 2003).

More importantly, the disposal of the used geothermal fluid to surface waters and/or to the sea creates serious environmental implications because it often contains significant quantities of pollutants, such as heavy metals. A typical geothermal power plant has relatively low GHG emissions. However, the emission of toxic pollutants such as ammonia, hydrogen sulfide, and boric acid can have a more substantial effect on surrounding vegetation (Gasparatos et al. 2017). It may also release elements such as radon, helium, arsenic, mercury, boron, the levels of which depend on the local conditions and geology (Barbier 1997, Bravi 2014). The effect of such emissions has been studied extensively in the literature with scholars attempting to assess the precise impact (Loppi et al. 2006, Manzo et al. 2013). In case of the existence of arsenic in local geological formations, geothermal installation and operation may be responsible for an elevated level of discharge in the surrounding area (López et al. 2012)

Moreover, geothermal power plants emit heat; the waste heat contained in disposed of used (waste) water can affect the temperature of surface waters. This may have serious impacts on the ecosystem, although research on this appears to be lacking. Modern geothermal power plants recycle the geothermal fluid and implement a multiple-use approach, which can include exploiting the heat content of the used water for applications such as district heating. At the same time, the temperature of the used geothermal fluid is lowered, mitigating the possible impacts.

Recharging the aquifer partially mitigates the physical effects induced by excess groundwater withdrawal. Apart from water quantity and quality issues, this also includes land subsidence which is not uncommon in geothermal developments. Although there is evidence that a certain ground settlement occurs in almost every geothermal plant, the magnitude of this can vary (Allis, 2000). In general, subsidence is largely stopped by water injection.

Noise is mainly related to the drilling phase and especially when discharging boreholes. Typically, the operation of a geothermal power station involves only low levels of noise. The visual impact is generally low, and there are even examples of geothermal stations attracting visitors (e.g., Iceland). In any case, installations should be designed in harmony with the surrounding area, especially in cases where the geothermal field is located in areas of natural beauty.

Geothermal development often needs to overcome negative community reactions. In some cases (e.g., the island of Milos, Greece) opposition resulted from previous bad experiences of pilot applications in the area. Unsuccessful pilot installations, especially if they do not adopt state-of-the-art technology that mitigates the mentioned environmental impact, have repeatedly affected the reputation of geothermal installations. Evidence of social opposition exists in several countries (Dowd et al. 2011), and the importance of this obstacle was highlighted and assessed in the EU-funded GeoElec project (2011-2013). Accordingly, a report on public acceptance has collected the relevant experience (Reith et al. 2013).

3.6 Biomass for electricity and heat production and biofuels

3.6.1 Description of the technology

Bioenergy for heat and power

Bioenergy includes a number of different approaches and conversion technologies that are used to produce electricity and heat. This includes thermochemical procedures such as combustion, pyrolysis, gasification, hydrothermal processing as well as biochemical processes (i.e., anaerobic digestion to produce biogas). Thermochemical processing of biomass varies significantly in size and technology used. Direct combustion and biomass use for heating are the oldest energy sources; combustion of biomass in steam turbines is used to produce electricity and may involve complex system design. Bioenergy sources for heat and power are very diverse including residues from forestry and agriculture sectors as well as municipal waste (waste-to-energy/WtE) and wastewater. In general, the electricity generation efficiency of biomass-based steam turbines is lower than that of conventional fossil-fuel plants, generally between 20% and 30%, with the higher values corresponding to biomass power-plants of larger power capacity. Biomass co-firing combines the combustion of biomass with that of conventional fossil fuels, usually coal or natural gas, to increase the energy content and efficiency.

In 2017, the global use of biomass for electricity and heat generation reached a total power capacity of 122 GW for electricity and 314 gigawatts-thermal (GWth) of heating capacity (REN21 2018a). China is the leading country in bioelectricity production, followed by Brazil, Germany, Japan, the United Kingdom and India (REN21 2018b). The EU hosts 17.35 GW of electrical capacity of solid biofuels (including wood and other solid wastes), 11.41 GW of biogas power capacity and an additional 1.78 GW of liquid biofuels used for electricity production. This total of 30.54 GW of bioenergy produces an annual 110.254 TWh.

Biofuels

Biofuel production and use are very concentrated geographically; over 80% of global production and use occur in the United States, Brazil and the EU (REN21 2018a). Biofuels for transport are categorised as either first-, second- or third-generation depending on the feedstock and conversion technology. First-generation biofuels are a well-developed technology mainly based on maize and sugarcane bioethanol also rapeseed and palm oil for biodiesel. The main biofuel products are ethanol (65%) and biodiesel (29%). Recent effort has focused on second-generation biofuels using feedstocks not suitable for human or livestock consumption; these are still in the pilot phase. Third-generation biofuels based on algae are at an early stage of development. Biofuels can also be classed as “conventional” (first-generation) or “advanced” (second- or third-generation). Advanced biofuels also deliver substantially higher GHG emission savings. Biofuel production, consumption, and trade are affected by factors including consumption trends in producing countries, global oil prices, political conditions, etc. They are also affected by policies and trade agreements such as the "anti-dumping" tariffs introduced by the United States on biofuel imports from Indonesia and Argentina. In Europe, however, the EU ended tariffs on imports of biodiesel in 2017.

In 2017, global biofuel production was 143 billion liters, the equivalent of 3.5 EJ. The annual biofuel production in the EU was 21.3 billion kg in 2016 (internal EC document). It is notable that production has slightly declined since 2010, reflecting the associated environmental impacts that are also illustrated in recent policy decisions.

3.6.2 Biodiversity impact of bioenergy

Natural biomass resources are limited, and their exploitation often competes with other productive uses. Biomass availability and environmental impacts are the major obstacles to bioenergy deployment. Biomass has a high number of different applications, including electricity production, heat production, biofuels for the transport sector (including aviation) and biochemicals. Bio-energy can play an important role in the transition towards a low-carbon energy system. However, it is important to ensure its sustainability. The Global Bioenergy Partnership has developed a number of sustainability indicators for bioenergy to minimize environmental impacts (GBEP 2011). Similarly, the United Nations Food and Agriculture Organisation (FAO) has coordinated a set of bioenergy sustainability initiatives under the Bioenergy and Food Security Criteria and Indicators project (BEFSCI). Bioenergy is associated with the following risks:

- Biodiversity loss, including deforestation
- Decreased water quality and availability
- Changes to land use
- Soil degradation, erosion and thus decreased crop productivity
- Life-cycle GHG emissions

The expansion of the land used to cultivate the biomass feedstock results in habitat and biodiversity loss. This effect is exacerbated by the use of monocultural cultivation strategies for feedstock. Changing the landscape to cultivate feedstock may also affect the soil quality, result in deforestation and alter the landscape (Pedroli et al. 2013, Kline et al. 2015). For this reason, bioenergy feedstock grown in degraded land is generally prioritized over irrigated “greenfield” biomass. Apart from minimizing the biodiversity impacts, such an approach mitigates the land use competition between energy and food production.

A recent approach to sustainable bioenergy investigates cultivating biomass for fuel using desert lands irrigated by seawater (Abideen et al. 2011). This type of approach allows the exploitation of areas inhospitable for conventional crops (Falasca et al. 2014).

In addition, there are likely to be impacts associated with increased demand for agricultural production, changes to land use, soil degradation, erosion and thus decreased crop productivity, and life-cycle GHG emissions.

Decreased water quality and availability

The increased agricultural activities associated with biofuel feedstock production raise serious concerns regarding their potential impacts on regional and local water resources with consequences for aquatic ecosystem health and also human water uses (Diaz-Chavez et al. 2011; De Fraiture et al., 2008; Donner & Kucharik, 2008). However, the water quality impacts of cultivating conventional crops as feedstock for first-generation biofuels are the same as from other farm crops (Diaz-Chavez et al. 2011). This may include intensive use of fertilizers and different types of pesticides (herbicides, insecticides, fungicides) and other malpractices in agriculture, such as tillage of unsuitable soils.

Life-cycle GHG emissions

Several life-cycle assessments (LCAs) have demonstrated that most biomass energy production pathways emit GHGs and atmospheric/ water pollutants that can have negative effects on ecosystems and biodiversity (Gasparatos et al. 2017). However, the type and level of emissions (and thus the extent of the environmental impact) vary considerably between different biomass energy options. For example, different LCAs have demonstrated the highly variable global warming potential of different biomass energy options [IPCC 2011]. Important factors that may affect the emissions include the conversion technologies, yields, feedstock and pollution control mechanisms (Gasparatos et al. 2017). Cherubini and Strømman (2011) performed a review of the bioenergy LCA literature summarizing and discussing the abundance of studies dealing with the different biomass resources, conversion technologies, products, and environmental impact categories.

Changes to land use

According to IEA (2011), less than 1% of global agricultural land is used for cultivating biofuel crops, and land use change associated with bioenergy represents a very small percentage of overall change (IEA Bioenergy 2011). However, direct and indirect land use change can have important climatic effects, both due to GHG emissions and the alteration of local micro-climates following changes in albedo and evapotranspiration (Gasparatos et al. 2017).

3.7 Batteries for Stationary Storage systems and Electro Mobility

3.7.1 Background

Current debates on energy stored in batteries focus on their use in two major technological applications: a) stationary storage systems and b) electromobility (e-mobility).

Presently, leading stationary storage solutions include the lithium-ion battery (LIB), sodium-sulfur batteries, supercapacitors, and flow batteries, and pumped storage and flywheels. Market forecasts for batteries for stationary storage applications in Europe start from an installed capacity of 5.3 GW in 2016, increasing to 7.6-9.8 GW in 2020 and 11.5-14.5 GW in 2025 (Kessels et al. 2016). These numbers, in the unit of power (GW) instead of energy (GWh), indicate growth factors of 1.6 till 2020 and of 2.5 till 2025.

For e-mobility applications, LIBs are considered to be one of the most popular types of rechargeable batteries. In particular, lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or NMC) batteries are the most commercially relevant types of LIB because, compared to other types of rechargeable batteries, they offer lower energy density but longer lives and reduced risk of fire, explosions, etc.

Stationary Storage

Stationary storage applications, also known as distributed energy storage, are widely recognized for their role in facilitating a real-time balance between electricity demand and production at a consumers' or network operators' premises. Their use complements renewable generation by smoothing out power fluctuations. In this context, stationary storage technologies may enhance prosumers' flexibility and increase the value of self-consumption. Smart grids can provide the necessary infrastructure and software solutions to connect the high-performance storage to the grid, and can also manage the charging and discharging of these distributed storage assets. This control of local storage is to ensure that the real-time balance between electricity demand and production at a consumers' site is effective.

Electro Mobility

Electromobility, more commonly known as e-mobility, is a general term which encompasses all technologies, products, services, and infrastructure that support and power all electric and hybrid vehicles. Currently, the e-mobility industry focuses on the development of electric-powered drivetrains designed to shift vehicle design away from the use of fossil fuels. Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs) are starting to command shares of the vehicle market and may eventually replace combustion engine vehicles. Market forecast numbers for energy demand of e-mobility in Europe range from 14 to 24 GWh in 2020 and from 37 to 117 GWh in 2025, with the lower estimate corresponding to a conservative scenario and the higher estimate to an optimistic scenario (Nationale Plattform Elektromobilität 2016). The forecast average corresponds to around 22% of the global e-mobility market in 2020, increasing to around 35% in 2025.

Some experts also tie the emergence of e-mobility designs to the idea of smart grids (SG). In this context, EVs and PHEVs may be used as storage facilities to offer possibilities for enhanced grid management and associated services through the Vehicle to Grid (V2G) application. V2G refers to the reciprocal flow of power between an electric vehicle (EV) and a recipient that could be, among other possibilities, the grid, a low voltage microgrid or a building. Furthermore, V2G offers the possibility of increased use of localized renewables. V2G application, with the dynamic adaptation of a charging/discharging cycle in response to the price signal, is a very promising technology.

3.7.2 Biodiversity impact of batteries

Stationary storage and EVs could be smartly coordinated with the production of local distributed energy resources to reduce the peak load on the power grid while not causing spikes in greenhouse gas emissions. As such they may be seen as a complementary technology for intermittent RES such as wind or solar electric. The main idea behind the aggregation of storage is to store electricity when demand is low relative to the power supply and inject stored electricity into the system at peak loads or to compensate fluctuating output of RES generation. Lastly, stationary storage and EVs can indirectly support the grid with intelligent charging to provide power to help balance loads by "valley filling" (charging at night when demand is low).

Batteries as storage systems can increase the GHG emissions at two stages of their life-cycle: the production, operation and disposal/recycling stages.

The potential GHG impact of battery production has been extensively explored in the literature. Peters et al. (2017) have assessed the overall environmental impact of production based on a number of different studies. When the authors averaged the data of all the existing studies, the total mean GHG emissions associated with the production of 1Wh of storage capacity battery was found to be 110g CO_2 equivalent.

Batteries may also increase GHG at their operation stage. While energy storage batteries can provide a wide array of services to the grid (as discussed above), they could also be used for energy arbitrage — storing energy when it is cheap and discharging it when it is more valuable (Hittinger and Azevedo 2015). There are two main reasons why energy storage deployed for arbitrage may increase emissions. First, storage increases the value of the energy sources it draws from and decreases the value of the energy sources it competes against when discharging. If the energy sources it draws from are more carbon-intensive than the energy sources it competes against, then it will have the effect of increasing the carbon intensity of the overall power mix. Second, every bit of energy stored also represents a bit of energy lost[14]. For instance, in the case of LIBs for every one megawatt-hour put in (stored), 0.80 megawatt-hours are produced (VOX 2018).

In 2015, the world's total LIB cell manufacturing capacity amounted to 60 GWh and was primarily located in China, Japan, and Korea (Lebedeva et al. 2016). Together, these countries hosted 88% of the total global LIB cell manufacturing capacity for all end-use applications. Although manufacturing processes are taking place in East Asian countries, mining for nickel and lithium involves countries such as Australia, Canada, Indonesia, Russia, and the Philippines. For instance, NMC lithium-ion batteries, which are widely used in the electro automotive industry, are a nickel-based product. The extraction of nickel involves environmental and health costs. The mining and processing of nickel-rich ores can generate significant quantities of aerial dust containing high concentrations of potentially toxic metals, including nickel, copper, cobalt, and chromium (Guardian 2017).

The increasing use of LIB is expected to cause a rise in the price of lithium, which might stimulate the exploitation of new lithium resources. The unexploited reserves of concentrated lithium of the world which are mainly in shallow saline lakes in the high elevation Andean deserts of Argentina, Chile and Bolivia may be put at great risk in the near future (Sutherland et al. 2011). For instance, the Salar de Uyuni salt flat in Bolivia, which contains almost half of the known lithium reserves, is currently exploited on a small scale by a Bolivian state corporation; however, more intensive extraction is planned (Creamer media Mining Weekly 2010). In this context, a large increase in the extraction of lithium, including the installation of mining and transport infrastructure may have great environmental impacts. These include considerable threats to species that inhabit the lakes in the high elevation Andean deserts, including the globally threatened Andean Flamingo (*Phoenicoparrus andinus*).

3.8 Summary of impacts of key energy technologies in the EU

We briefly summarise the biodiversity and SDG impacts of EU-supported RETs derived from the scientific literature, through a non-systematic review. In this step we consider only negative impacts, due to time

[14] The "round-trip efficiency" of energy storage — the amount of energy it releases relative to the amount put in — ranges, depending on the technology, from around 40 to 90 percent. (https://www.vox.com/energy-and-environment/2018/4/27/17283830/batteries-energy-storage-carbon-emissions)

constraints, contrasting with the workshop, in which positive impacts are also considered. The impacts identified in this step are then combined in a conceptual model, as detailed below (see Appendix VI).

3.8.1 Biodiversity loss

It has been argued that a degree of short-term biodiversity loss associated with renewable energy development must be accepted in order to avoid the greater long-term loss that would accrue from climate change and from development of fossil energies: opencast coal mines, tar sands (see, e.g., Jackson 2011). However, the exact impact of Renewable Energy Technologies (RETs) development will depend on the installation site as well as the scale of development. Biodiversity impacts can be minimized by strategically siting renewable energy developments. The scale of RET installations may lead to low, medium or high biodiversity impact. Low-risk technologies include rooftop solar, thermal and photovoltaic panels, and heat pumps (air or ground source). Medium-impact technologies include onshore wind, bioenergy crops, solar farms, offshore wind (fixed base and floating turbines), wave power and tidal stream. High-risk technologies include new large-scale hydropower schemes (e.g., those that create artificial reservoirs (Rosenberg et al. 1997)) and certain tidal range technologies (particularly shore-to-shore barrages (Wolf et al. 2009)).

Impact of various Renewable Energy Technologies on the SDGs

Through a non-systematic literature review, we identify the main mechanisms of ecosystem change and biodiversity loss for each renewable energy pathway, namely solar PV, wind, hydro, bioenergy, marine, and geothermal energy. These regional and global biodiversity impacts of each renewable energy pathway are linked to relevant Sustainable Development Goals (SDGs). We do not consider the positive impact of RETs on biodiversity, such as the obvious reduction in GHG emissions (ceteris paribus), focussing only on negative impacts such as the contribution of RET to GHG emissions during its manufacturing or disposal phase. Similarly, we consider only the negative impact of RETs on the attainment of SDGs that are closely linked to biodiversity. In this context, considering the most prevalent drivers of ecosystem change and biodiversity loss due to renewable energy expansion, each of the different renewable energy pathways reviewed and their associated impact on ecosystem change and biodiversity loss can be linked to at least one of five key SDGs:

- SDG 3: Good health and well-being
- SDG 12: Responsible consumption and production
- SDG 13: Climate action
- SDG 14: Life below water
- SDG 15: Life on land

Renewable energy installations have at times undermined the achievement of the SDGs through ecosystem change and biodiversity loss. Living organisms across all ecosystem types receive some of the most prominent negative impacts, including physical displacement, habitat loss, habitat change, toxic pollution and disturbance (noise, visual and heat pollution). Given the urgency and scale at which renewables must be deployed to meet the world's climate goals, it is especially critical that we understand their potential negative impacts on each SDG, to ensure that renewable energy driven development does not come at the expense of other SDGs. To explore the links between RETs, biodiversity, and SDGs we have constructed Table 1. Each of the different renewable energy pathways reviewed and their associated impact on ecosystem change and biodiversity loss can be linked to at least one of these key five SDGs. In the following sections, we associate each SDG with the technologies causing the highest impacts and provide a short description of these impacts. Full impacts of RETs on each SDG are presented in Table 3 (Appendix VI).

SDG 3: Good health and well-being

This SDG aims to ensure healthy lives and promote well-being for all at all ages. Health and well-being also include targets related to the prevention of deaths and injuries from hazardous chemicals and air, water, and soil pollution and contamination.

Bioenergy: The burning of biomass presents a source of air pollution. Lung specialists, public authorities stress the health risks entailed in the burning of biomass, whether indoors or outdoors. For example, burning sugar cane straw is a common practice in several regions of Brazil and is leading to respiratory problems in the exposed population.

Hydropower: Resettlement of villages and people can result from the building of dams (e.g., the case of Binh Thanh commune in central Vietnam due to the building of the Binh Dien hydroelectric dam on the Huu Trach River).

Solar PV: The manufacturing of PV modules can potentially result in toxic chemical generation posing serious public health threats. These include damage and disease in the lung and pulmonary system, central nervous system, endocrine system, cardiovascular system, and kidneys.

SDG 12: Responsible consumption and production

This goal articulates targets to ensure sustainable consumption and production patterns. Energy technologies affect the attainment of this goal in terms of the amount and scarcity of raw material and natural resources used in their manufacture.

Solar PV: The production of photovoltaic panels requires common minerals such as iron, copper, and aluminum as well as the use of scarce materials such as telluride, indium, cadmium, and gallium (even though the required quantities of scarce materials which may be needed are small[15]).

Tidal Barrage: Tidal barrages are essentially dams stretching across the full width of a tidal estuary. The construction of a tidal barrage requires a vast quantity of raw materials, mainly concrete and steel, to withstand the huge loads produced from dammed water.

SDG 13: Climate Action

This goal articulates targets to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.

Biomass: Several life cycle assessments (LCAs) have demonstrated that most biomass energy production pathways emit GHGs and atmospheric/ water pollutants that can have negative effects on ecosystems and biodiversity. Atmospheric emissions from biomass energy value chains can also contribute to tropospheric

[15] Although the needed quantities of scarce materials are small the processes may involve the mining of huge quantities of other minerals.

ozone formation. Such emissions have been confirmed for key biomass energy species such as eucalyptus, poplar, and willow as well as short rotation coppice and wood pellets (Carreras-Sospedra et al. 2015).

Biofuels: Similar to bioenergy, comparative LCAs have confirmed that different biofuel options can have widely divergent GHG emissions depending on the feedstock, agricultural production practices, and production area (Manik, Yosef & Halog, Anthony, 2013).

Hydropower: There is scientific evidence that the emissions contribution of the submerged organic matter, following the filling of the reservoir, may be larger than expected (Fernside 1995; Gunkel, 2009; Fearnside 2015). Hydropower plants can emit a large amount of GHGs, mainly carbon dioxide and methane from reservoirs (Gasparatos et al. 2017). These emissions can be comparable (or even higher) to those of conventional power plants.

SDG 14: Life below water

This goal articulates targets for conserving and sustainably using the oceans, seas and marine resources for sustainable development. Habitat change/loss and wildlife loss are the most prevalent drivers which may hinder the attainment of SDG 14.

Hydropower: In terms of habitat loss/change, hydropower installation may cause alteration of water flows, disrupt fish migratory routes and induce changes in sediment loading, turbidity, and eutrophication.

Tidal Barrage: In terms of habitat loss/change the installation of a tidal barrage may induce the permanent inundation of the upstream portions of estuaries and affect sediment loading, salinity, and water turbidity. In terms of wildlife loss, tidal barrages could entrap species, (e.g., whale entrapment at the Annapolis plant in Canada) or even contribute to the creation of harmful algal blooms which may threaten the existing plankton communities.

SDG 15 Life on land

This goal articulates targets for preserving the biodiversity of the forest, desert, and mountain ecosystems, as a percentage of total land mass. Additionally, SDG 15 calls for more attention to preventing invasion of introduced species and more protection of endangered species. Habitat change/loss and wildlife losses are the most prevalent drivers of ecosystem change and biodiversity loss due to renewable energy expansion, hindering the attainment of SDG 15.

Bioenergy/biofuels: In terms of habitat loss/change, the extensive use of bioenergy and biofuels may lead to loss and fragmentation of habitats due to land conversion into monocultural agricultural landscapes. Additionally, the expansion of bioenergy and biofuels may result in the invasion of some feedstock species (e.g., eucalyptus, miscanthus) that compete with native vegetation.

Hydropower: Hydropower is responsible for the flooding of upstream areas. This can submerge ecosystems, fragment habitats and affect estuarine nature reserves. Additionally, this may lead to deterioration of landscape, vegetation, and wildlife.

Wind: In terms of wildlife loss, the installation of large-scale wind farms may cause bird & bat collisions (barotrauma to bats). In term of habitat loss, the installation of large-scale wind farms may disrupt the migratory routes of some bird and bat species.

Solar PV: Since large-scale solar PV requires the occupation of a large area of land, this may displace some of the traditional uses of the land like greenfield and agricultural use (loss of cultivable land). Additionally, the clearing and use of large areas of land for solar power facilities can lead to habitat loss.

Table 1: Key impacts of Renewable Energy Technologies in the EU, based on the literature review. Impacted SDGs common to all RETs are shown here in detail. Impacts are categorised according to whether they are regional or global, type of impact, and affected SDGs.

RET	regional impact		global impact	
	type	SDG	type	SDG
tidal barrage	**wildlife loss:** species entrapment and threat to plankton **habitat loss/change**: permanent flooding of upstream parts of estuaries, changes in sediment loading, salinity and water turbidity	14:LBW	natural resources: vast quantity of concrete and steel	12:SCP
solar PV	visual pollution **hazardous material**: public health threats	3:GHW	natural resources: scarce raw material	12:SCP
	habitat loss/change: a) land use competition: farming/greenfield or to be maintained as areas of wildlife, fauna, and flora. b) degradation: clearing and removal of upper soil layers **hazardous material**: environment	15:LOL	GHG emissions: manufacturing phase	13:CA
wind	noise and visual pollution	3:GHW	natural resources: ≈95% steel and fiberglass	12:SCP
	local climatic conditions	13:CA	GHG emissions	13:CA
	wildlife loss: bird & bat collision, barotrauma to bats **habitat loss/change**: disrupt the migratory routes of some bird and bat species	15:LOL		
bioenergy/ biofuels	air pollution: changes in the respiratory morbidity standards of the population exposed	3:GHW	GHG emissions: for some pollutants and contexts higher than fossil fuels. Hard to quantify GHG produced due to ILUC	12:SCP
	land use competition (loss of agricultural land, natural land, e.g., forests, grassland), leading to loss of biodiversity	12:SCP		

	fertilizers and agrochemical runoff lead to water pollution and eutrophication	14:LBW		
	habitat loss/change: a) can affect local microclimates. Oil palm plantations have low biodiversity and replace primary and secondary forest. 2nd generation biofuels support more habitat and biodiversity than the 1st generation. **b)** some biofuels, e.g. perennial grasses, can be invasive	15:LOL		
hydropower	**habitat loss/change**: **a)** flooding of upstream areas sinks ecosystems, fragments habitats and impacts estuarine nature reserves	15:LOL	GHG emissions	13:CA
	habitat loss/change: b) alters water flows , **c)** disrupts fish migratory routes**, d)** changes sediment loading, turbidity, and eutrophication	14:LBW	natural resources: mainly concrete and steel	12:SCP
	need for resettlement of local communities due to dam construction	3:GHW		
geothermal	**habitat loss/change**: only in highly biodiverse and/or fragile ecosystems. **a)** surface disturbances may occur during drilling, **b)** toxic pollutants such as NH_3, H_2S, and boric acid	15:LOL	GHG emissions: minor effect	13:CA
	water table: affects/transforms existing hot springs heat pollution: increased temperature of surface waters	14:LBW		
	noise and visual pollution	3:GHW		

We next developed a sample conceptual model based on the scientific literature, using Mental Modeler. This was carried out in order to guide the process of constructing models in the workshop, and to provide a potential basis for comparison. To do this, we first assess the relative RET impacts on a given SDG, comparing RET installations with similar capacities. We consider installations of large-scale (utility-level) RETs, with capacities of some hundreds of MW. In this context, especially for solar PV and wind energy, the comparisons may involve large scale wind or solar farms with tidal barrage and hydropower stations of almost equal capacities. Nevertheless, comparing at the same scale of capacities, the extent of risks and opportunities associated with renewable energy development is highly dependent on the type of RET harvested. Different RETs have very different biodiversity impacts; for instance, bioenergy is a much greater threat to biodiversity than solar and wind. This model only considers biodiversity impacts as components of relevant SDGs.

After considering the findings of the literature review for the (negative) impacts of each RET on the SDGs, we qualitatively assess these relative impacts and assign scores between -3 and 3 to each impact (according to the ICSU scale). These impacts are presented in Table 3 (Appendix VI). For this sample model, we consider only negative impacts due to time constraints. We then consider the contributions of individual subimpacts of the RET on an SDG, based on the literature review. The impact scores are then divided by 3 to conform to the Mental Modeler scale (-1 to 1) and used as the corresponding weights of a link between the RET and an SDG to construct the model shown in Figure 27 (Appendix VI). The impacts identified through this process are broadly similar to those obtained through the expert workshop, providing a degree of confidence in our conclusions.

4. Findings from an expert workshop on renewable energy sources (RES) and their potential impacts on global biodiversity and the Sustainable Development Goals (SDGs)

The second part of this report concerns a workshop organised between 19 and 20 November 2018. The goal was the development of an integrated model of experts' knowledge of the system in which EU policies related to renewable energy sources may impact global biodiversity and the targets of the UN SDGs. The workshop agenda and list of participants and their affiliations can be found in Appendix I and II respectively. The integrated model was based on the participants' individual models created in the workshop; these are shown in Appendix IV. Participants represented the scientific community (universities and research organisations), as well as international organisations, public bureaus, and non-governmental organizations (NGOs).

Date and location

19-20 November 2018 (two half-days), Brussels Office of the Helmholtz Association, Brussels.

Organising committee: Dr Miriam Grace, University of East Anglia – EKLIPSE; Dr Marianne Darbi, UFZ Helmholtz Centre for Environmental Research – EKLIPSE; Dr Alexis Meletiou, UFZ Helmholtz Centre for Environmental Research – EKLIPSE; Dr Henri Rueff, Centre for Development and Environment, University of Bern; Ms Myriam Pham-Truffert, Centre for Development and Environment, University of Bern.

Figure 2: Opening of the workshop

4.1 Key findings

The main findings discussed in the workshop are outlined here:

After careful analysis and group discussions, a number of key points were identified:

1. Role of renewable energy technologies:

Renewables play a major role in decarbonisation and climate change mitigation strategies. Still, there are important aspects and considerations that need to be taken into account to avoid potential ecological impacts. This includes scale, which in certain technologies was identified as a proxy of the potential ecological impacts.

2. Best installation practices:

The ecological impact of renewable energy technologies (RETs) is related to designed systems. Accordingly, best practices must be identified and prioritised in order to produce clean energy with the minimal environmental footprint. This includes the selection of sites, utilisation of degraded and brownfield land as well as alternative and/or evolutionary approaches for both the electricity and transport sectors.

3. Integrated approach:

Energy policy needs to also consider other sectors and potential interactions in an integrated manner. Approaches such as the water-energy-food nexus (WEF) analyses allow to better understand the trade-offs between water provision, energy, and food production as well as the impacts on the ecosystem.

4. Manufacturing process:

The use of materials and their disposal after the end of the systems' lifetime need to be taken into account. Technological breakthroughs have already resulted in decreases in requirements for materials and energy in the manufacturing process. The resulting cost reductions allow a wider deployment of RETs.

These findings are indicative of the complexity of the ongoing process to reach a carbon-neutral energy sector. Policies to mitigate climate change by reducing greenhouse gas (GHG) need to avoid environmental impacts and minimise the possibilities for indirect impacts and/or cumulative effects.

4.2 Description of the approach

On the first day of the workshop, the participants were guided to identify key terms (concepts) relating to the renewable energy policies, technologies and their impacts, followed by the linkages between each of them. This information was used to structure the model components and their interactions in a graphical form. To do so, a Fuzzy Cognitive Mapping (FCM) approach was followed. The FCM methodology offers techniques that allow for transparent and systematic integration of maps produced by multiple participants. For each map, the variables and their relationships can be represented in an adjacency matrix.

Participants were asked to code the impacts on ecosystems based on biome type, after Olson et al. 2001 for natural biomes and Ellis et al. 2008 for anthropogenic biomes (see Appendix III). More detail on these biome types is available at WWF Ecoregions[16].

On the second day, following the development of each participant's graphical model (see Appendix IV), the invited specialists were divided into three breakout groups of six people each. The division was made in a way that supported an even representation of the various sectors and specialties to cover gaps in experience and enhance cross-fertilisation of knowledge and ideas. Further, for each group, two facilitators, members of the organizing committee, carried out moderation, note-taking, and documentation. Each group brainstormed using the previously developed graphical models and discussed the potential impacts of different RES and their extent. Various guiding questions were used to trigger discussions such as the following:

- what is already documented
- potential unforeseen or less known aspects
- whether they had focussed on local or global/telecoupling effects
- potential indirect or cumulative effects
- priorities in certain RES technologies
- knowledge gaps

The individual group discussions aimed to identify the SDGs that current EU energy policies try to pursue as well as the systemic trade-offs and benefits.

Moreover, the experts discussed possible policies and governance mechanisms that could remedy the negative impacts and enhance the positive ones. The present document collects and summarises the input of the invited experts and, thus, aims to facilitate its use by the scientific community, triggering further research and analysis. Accordingly, it reflects the input of the invited specialists in a non-biased manner. For each group, the collected and recorded information is organized according to the RES technology discussed.

4.3 Documentation and findings of Day I

During the first day of the workshop, the participants developed their models using the FCM approach, based on the freely available Mental Modeler software. Following an explanation of the methodological approach and a short training on Mental Modeler, each specialist developed her/his model during the afternoon session. The models were saved and collected in order to be analysed, discussed and/or updated during the second day of the workshop.

[16] Available at www.worldwildlife.org/biomes

Figure 3: Participants creating their individual models during the first day

The specialists thus exchanged their views on the developed models, triggering further discussion and analyses. Highlights of these discussions are:

Biomass

An example of RES interactions with the ecosystem is the cultivation of biomass (bioenergy crops) in peatlands. This observation triggered further discussions on day 2 but also allowed early identification of the implications for SDGs. The discussion also highlighted the need to suggest specific solutions and optimal strategies to avoid negative impacts.

Tree plantation was also highlighted as a climate mitigation strategy. It was considered important, however, to prioritise best practices over less efficient ones and include them in the modelling activities.

Solar photovoltaic (PV) systems

The complexity of the interactions of the RETs with the ecosystem was also underlined. As an example, the participants presented the role of previous land use/cover in the case of solar PV system installation. The implications are different in case of arable or brownfield land and natural grasslands. Accordingly, the impacts can be more on the positive or negative side.

Apart from the land use the parameters of scale, boundaries were also highlighted both for solar PV, wind energy and biofuel production.

Hydropower

Modelling work allowed the participants to focus on hydropower project development and the complex economic, environmental and social implications related to new dam construction. Efforts included balancing the model's theoretical dimension with reality.

Model advantages and limitations

The participants praised the ability of the model analysis to simplify and visualise a complex topic. It is an advantage that this approach is straightforward and has its merits, particularly if the model is kept lean. It also allows the user to decide on the level of detail for analyzing each component. Participants underlined the need to measure and assess the RETs in the context of the alternative energy sources, i.e., conventional, nuclear.

Some model limitations were also noted with the main one being the lack of the option to include the time dimension. This would also allow including impacts and interactions as they evolve over time. Increased model complexity was also mentioned especially in the context of the analysed issue. Qualifying and quantifying the RES–ecosystem interaction appeared to be a challenge. Participants mentioned the complexity of the issue and the cascading effect of a possible decision or a policy change in the system equilibrium.

4.4 Documentation and findings of Day II

4.4.1 Group A: Analysed renewable energy technologies

The participants highlighted the importance of RES in the global efforts to mitigate climate change, the reduction of GHG emissions and air quality. They also recognised the importance of every RET in the EU's industrial production and economy. It is important to understand what the stakes and the alternative solutions are: the need to produce clean energy-electricity, the technological barriers of emerging energy (sub-) technologies, the challenges related to the variability of production of modern RES and the various risks related to nuclear electricity production. Modern RES, hydropower, and bioenergy are presently the main means to produce clean energy. The ecological impact varies between technologies and also depends on the location of the installation and its size-characteristics. Accordingly, future installations need to be optimal not only in technical and economic terms but also in a way that minimises energy systems' ecological footprint.

Solar PV

The participants highlighted the need to determine what kind of land is used for the deployment of solar PV systems. This is particularly important for installations of large- or very large utility scale (e.g., 200 MW) where the requirements for land coverage become enormous. The use of degraded, brownfield land was highlighted, with some participants presenting their work on installations in closed or abandoned landfills, coal mines, existing infrastructure, etc. Such approaches were identified to solve multiple challenges potentially (e.g., land degradation, land value, waste management) while addressing the land needs of solar PV systems.

The technical characteristics of solar PV systems' installations have also been underlined as a source of potential environmental impacts. Specifically, it was mentioned that typical south-facing installations involve a certain distance between the racks (to avoid shading) that allows the soil and vegetation underneath the PV modules to receive sunlight and rain. Such installation practices were found to have superior ecological characteristics to east-west orientated arrays. The design of the latter has an impact on the ground underneath the solar panels because the rows are installed more tightly, creating roof-like structures that block natural light and rainwater from reaching the ground.

Accordingly, environmental impact assessments are required to analyse light and water levels as well as the soil content. This shows the need to better understand the interaction of solar PV systems and biodiversity in order to specify the impacts on biomes.

Breakthroughs in solar cell manufacturing and new PV technologies such as organic and thin film PV may allow higher efficiencies - meaning higher energy density - and advanced design strategies that allow installations in harmony with the landscape. Such progress will certainly allow further cost reductions that will render more locations (especially degraded land) cost-effective for solar PV installations. Rooftop PV systems were also highlighted as an approach to land use and ecological advantages. According to recent conservative scientific estimates, up to 25% of EU electricity needs could be potentially produced in rooftop solar systems installed in the existing EU building stock. The participants highlighted the need to endure that solar energy technology maintains its major role in the decarbonisation of the energy sector finding approaches and strategies with a low (ideally zero) ecological impact.

Participants considered that the deployment of solar energy technology, in the form of solar farms, may have a potentially positive and negative impact on the attainment of the following SDGs: 2, 3, 6, 7, 8, 13, 15 (see Appendix IV).

Hydropower

The required rapid transition to low-carbon, RES for electricity production always brings hydropower into the equation. As a mature technology that has provided clean electricity for more than a century, it is high in the development agenda of emerging economies. Further, the largest amounts of untapped hydropower potential are located in Africa, South East Asia, and South America. However, there is a risk that expanded investment in hydropower may trigger overly rapid dam construction, and approaches that do not consider the environmental and social implications can potentially damage river ecology, also including fish populations.

As an example, the participants commented on the ongoing plans of Poland to further develop its hydropower resources, commenting on the possible significant ecological impacts of new dam construction. Such considerations, however, must be set against the dramatic needs of Poland to decarbonise its power sector, which is highly carbon-intensive (700g CO_2eq/kWh). This dilemma complicates policy design.

The participants highlighted the decreasing costs of modern RES such as solar PV and wind energy and underlined the necessity for their extended deployment. Such installations will be supported by the unique flexibility and storage characteristics of existing hydro stations. New projects must be strategically planned and located in ways that minimise environmental and social disruptions. The practice of prioritising many small-scale hydropower stations over a larger one was also questioned. The cumulative impact of a large number of small stations can be higher than the impact of a carefully designed single station. Besides, large-scale hydropower projects generally have more resources than smaller ones, in terms of measurement equipment, technology, personnel, experience, etc., to monitor river ecology and react accordingly.

Bioenergy and biofuels

The discussions focused on bioenergy due to its complexity and a wide range of forms and applications. Cultivation of energy crops in arable land was highlighted as a risk factor for food production in terms of the WEF interactions. The participants highlighted the need to protect peatlands as valuable ecosystems for preserving global biodiversity. Such areas contain large, clean water resources; their vegetation minimises flood risk and stores carbon. Accordingly, it is important to protect such areas when developing plans for bioenergy crops. Besides, damaged peatlands can potentially become a source of GHG emissions, whereas peatland restoration can result in significant GHG emission reductions.

The impact of energy crops on deforestation was highlighted, mentioning the well-known case of palm oil production and its impact on tropical forests. Deforestation is directly related to water drainage and an alarming increase of floods and their associated impacts.

Alternative pathways thus need to be considered. The EU should not subsidise unsustainable cultivation practices, e.g., through the Common Agricultural Policy (CAP). The potential distorting role of national-level subsidies as a source of risk was also highlighted. The differences between first-generation biofuels and the - currently developed - second-generation were mentioned along with the plans to use algae in order to attain the third-generation of biofuels. Technological limitations, as well as the role of electro-mobility in creating a sustainable transport sector, were discussed.

The important role of bioenergy in "fragile countries" (a term some participants used to describe developing and low-income economies) was particularly highlighted. Traditional biomass is widely used in sub-Saharan Africa (SSA) for cooking. Biomass collection is, thus, a time-consuming process in many areas of the world, and also contributes to gender imbalance, since women are often tasked with collecting firewood, etc. Modernisation of energy supplies via, e.g., RES could also have a positive impact on social welfare on top of the obvious economic gains due to increased productivity. In such cases, energy policies can improve the role of women in society.

Finally, participants considered that the expansion of production of bioenergy and biofuels may have an important impact on the attainment of the following SDGs: 2, 3, 5, 6, 11, 12, 13, 15 (see Appendix IV).

4.4.2 Group B: Analysed renewable energy technologies

Solar PV

The participants of Group 2 focused on the importance of telecoupling effects of solar energy technology. They noted a number of negative effects such as:

- The intensive involvement of the extractive industry in the manufacturing process of PVs;
- PV system installations may induce land use competition for farming and food security issues;
- High pollution for birds during the operation of a solar farm.

On the other hand, participants noted the very positive effect which the installation of solar PV systems may bring to biodiversity.

The participants of Group B recognized that solar PV capacity' deployment would include both losers and winners. Human health is expected to benefit from the reduction in the use of pesticides and fertilizers. At the same time, large-scale deployment of solar PV may endanger food security, in certain sensitive regions. Additionally, the group of "losers" may include energy suppliers and grid operators. Energy suppliers may lose profits as consumers installing rooftop solar PV will become more self-sufficient. Grid operators may find it difficult to cope with all the additional energy; solar producers will feed into the system.

Participants considered that the deployment of solar energy technology may potentially have a positive impact on the attainment of the following SDGs: 2, 3, 15, 13, 9, 1 (see Appendix IV).

Wind energy

Initially, the participants of Group B described wind energy technology as a rapidly developing technology, highlighting its potential of improving in the near future. Then they focused on the importance of telecoupling effects of wind energy technology identifying two main forms: onshore and offshore. Onshore wind mainly affects landscape structure. On the other hand, offshore wind technology impacts biodiversity as well as landscape structure, and its manufacturing process may require high levels of extraction, e.g., mining. However, for both onshore and offshore wind, the precise biodiversity impacts of habitat fragmentation will depend on the scale of deployment. Concerning wildlife loss, the participants highlighted that wind farms can potentially reduce the abundance of predatory birds and bats but at the same time may increase lizard populations. Other negative impacts of wind farms may include noise and visual pollution, shadow creation, etc.

The participants mentioned that the manufacturing processes of wind energy sources may involve intensive energy use, particularly to transport heavy raw materials from the site of production to the site of installation. They also noted that the manufacturing processes may involve mining for lithium and rare earth metals. The installation of wind energy units may involve the occupation of huge areas of land.

The development of wind energy may include both losers and winners. Winners may include marginalized groups who may benefit from higher levels of education, increased equality and improved health conditions. Losers may include real estate agents.

Finally, participants considered that the deployment of both forms of wind energy may have potentially positive and negative impacts on the attainment of all the SDGs concerned, from 1 to 17 (see Appendix IV).

Hydropower

Initially, the participants of Group B argued that the magnitude of the effect of hydropower varies according to the size of the dam. Then, they stressed the importance of telecoupling effects of hydropower energy discussing a number of negative and positive effects. Negative effects can be summarized as follows:

- Fragmentation of landscapes which may destroy or disrupt fish migratory routes;
- High methane emissions as methane are produced at the bottom of the reservoirs, where oxygen is low, and bacteria decompose organic material, like trees and grasses;
- The flooding of areas which fragments habitats and disaffects nature reserves portions of estuaries;
- The decrease of fish and food stocks;
- The transport and changes in sediment loading, turbidity, and eutrophication.

However, participants also identified a number of positive telecoupling effects such as:

- The contribution of hydropower to the mitigation of the climate change problem;
- The contribution of hydropower to better water management.

In terms of mechanism and how hydropower contributes to the energy security of the grid, participants noted its contribution to grid stability. In this context, hydropower can be used when it is needed to support various sources of energy, including RES. In particular, participants mentioned the example of pumped hydroelectric energy storage which is a type of hydroelectric energy storage used by electric power systems for load balancing.

Participants realized that, as is the case with other RES, the deployment of hydropower involves both winners and losers. Winners may include the tourism industry as people may be interested in visiting large dams for recreational reasons while losers may include the local communities which may need to be resettled due to dam construction.

Finally, participants considered that the deployment of hydropower technology may have both positive and negative impacts on the attainment of the following SDGs: 15, 6, 2, 7, 13 (see Appendix IV).

Bioenergy and biofuels

Initially, participants of Group B noted that the effect of bioenergy and biofuel production strongly depends on the type of bioenergy and biofuel. Then, there was an interesting and extensive discussion on the telecoupling effects of bioenergy and biofuels, which benefited from the fact that many of the participants showed particular interest in the topic. Two main telecoupling effects were distinguished: biodiversity loss and land-use competition. Concerning biodiversity loss, the expansion of land used to cultivate the biomass feedstock results in habitat and biodiversity losses. Concerning land-use competition, there is evidence that shows that the extent to which biofuels compete with food for the limited land and water resources of the planet are becoming an additional obstacle to increasing food production in line with the growing needs of the human population.

Participants then focused on the cascading effect of biofuels on crop prices. In this context, there was an extensive discussion on the noticeable impact of biofuel production, like ethanol production, on individual crop prices.

Participants noted that bioenergy and biofuel production may have both winners and losers. Losers may include marginalized communities and people who suffer decreases in living standards due to deforestation. In more general terms, food insecurity is yet another issue that may negatively affect people. On the other hand, winners include only one class of stakeholders, biofuel producers.

Finally, participants considered that the expansion of production of bioenergy and biofuels may have an important impact on the attainment of the following SDGs: 13, 2, 8, 15, 7, 1, 3, 6, and 16 (see Appendix IV).

4.4.3 Group C: Analysed renewable energy technologies

The facilitators and participants addressed all the guiding questions set at the beginning of the group session. After synthesising their knowledge of specific energy technologies, the participants mainly focused on biofuel generation and less on hydropower and wind. The discussion included some of the following topics:

- the environmental, social, economic aspects of biofuels,
- the distinction of the biofuels effect on a local, national and global level,
- the analysis of winners and losers.

Bioenergy and biofuels

Through this interdisciplinary exercise participants of Group C addressed biofuel production impacts, noting that their models did not explicitly consider the level of uncertainty. They focused mainly on biofuel impacts in developing countries. They considered both general effects such as deforestation as well as more local effects (feedback loops and livelihoods). Additionally, based on work they were involved in, participants detected potential side effects, including current knowledge gaps. However, there was a high level of uncertainty regarding the strength of "potential" effects because these effects depend on the local context in relation to tenure, conservation policy, and agriculture. The promotion of biofuels may or may not be an opportunity to improve local livelihoods.

Some of the participants noted that there is too much agricultural production, so biofuel production can be a win-win situation with many winners. To achieve this, it is necessary for the biofuel industry to make use of residues of agriculture. For instance, biogas plants could be a solution; however, they consume food crops, but the impact is hard to measure. As participants tried to follow a more holistic approach, they observed that countries could do things differently. For instance, in Germany, there was an incentive scheme, for biofuels and it would have been better to adjust it rather than completely changing it. In this context, adjustments of policies, based on knowledge and experience, may be better than abolishment.

For some participants, winners and losers are at the top and bottom of a pyramid. For instance, corn crop cultivation can have impacts somewhere in Latin America (on forests, etc.). In terms of trade-offs, traditional partners can lose benefits. There may be an impact on plants and animals which in turn will induce biodiversity loss of an ecosystem degradation for the local people who rely on them. The policies can generate different impacts with different winners and losers. For instance, Germany has benefitted from energy for a long time. Winners may include those who implemented the technologies first, while the losers may include traditional partners.

5 Models of renewable energy sources' (RES) impacts on global biodiversity and the Sustainable Development Goals (SDGs)

5.1 Developing an integrated model

This model was generated from twelve of the participants' individual models. These were chosen based on the ease of integration and clear links to policy, biodiversity and SDG impacts. In two cases the model was not received in time for the integration; it is anticipated that these will be integrated into an updated version of the model for subsequent outputs. Integration focussed on developing common key terms across the models, which reduced the complexity of the final model. Interactions were adjusted in terms of the final impacts on SDGs so that they had either "positive" or "negative" impacts on achieving the SDGs.

The individual graphs, constructed in Mental Modeler, were exported as CSV files. These were imported into R to generate the base graph using the igraph package (Csardi 2006), with the weight of each link computed as the mean of the corresponding link across the twelve models. This graph was then exported into Gephi (Bastian et al. 2009) for advanced visualisation; the final integrated model is shown in Figure 4.

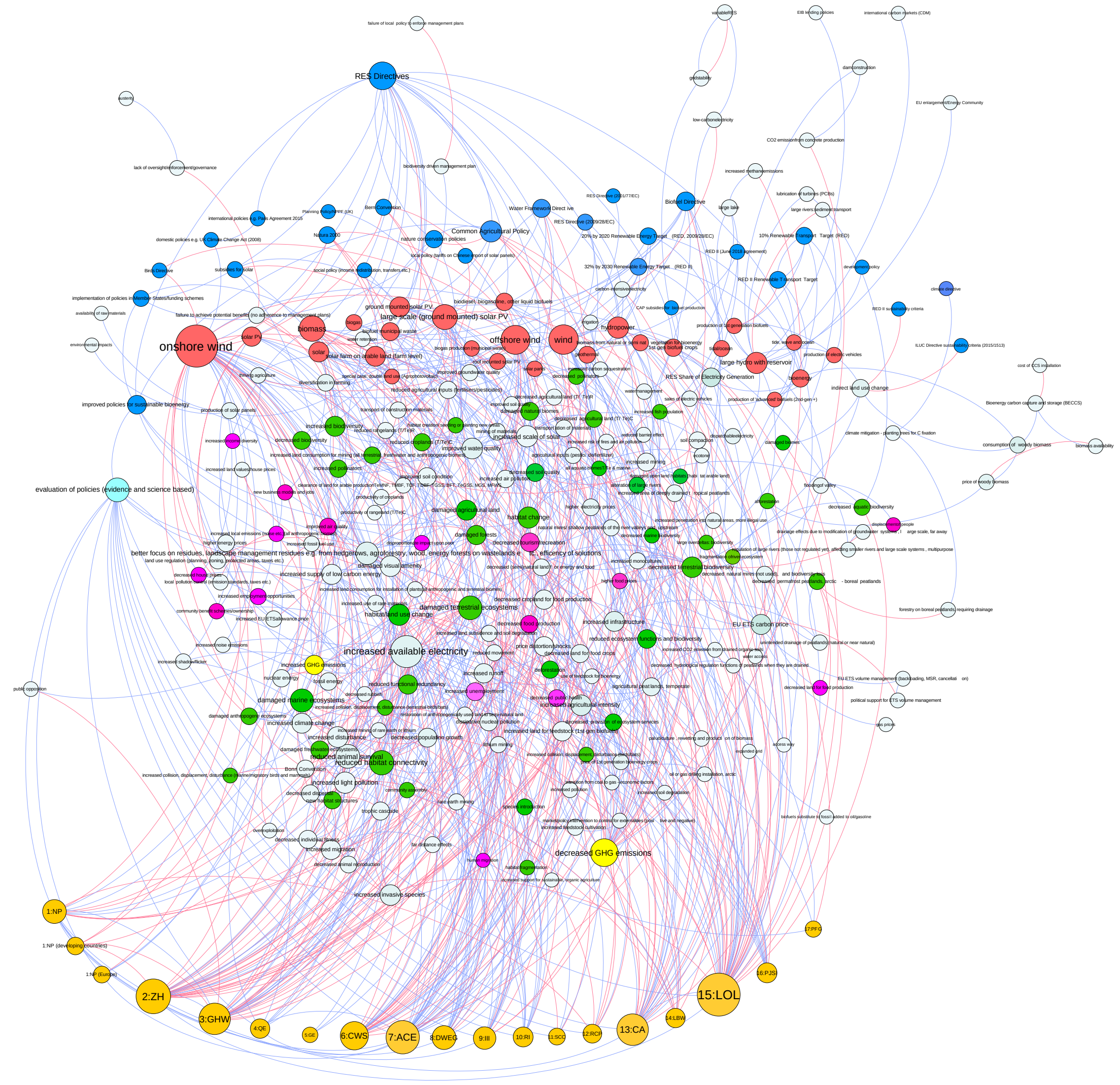

Figure 4: Integrated model of energy-biodiversity-SDGs interactions, with all nodes sized according to degree, and edges coloured according to the sign of the interaction (blue for positive, red for negative).

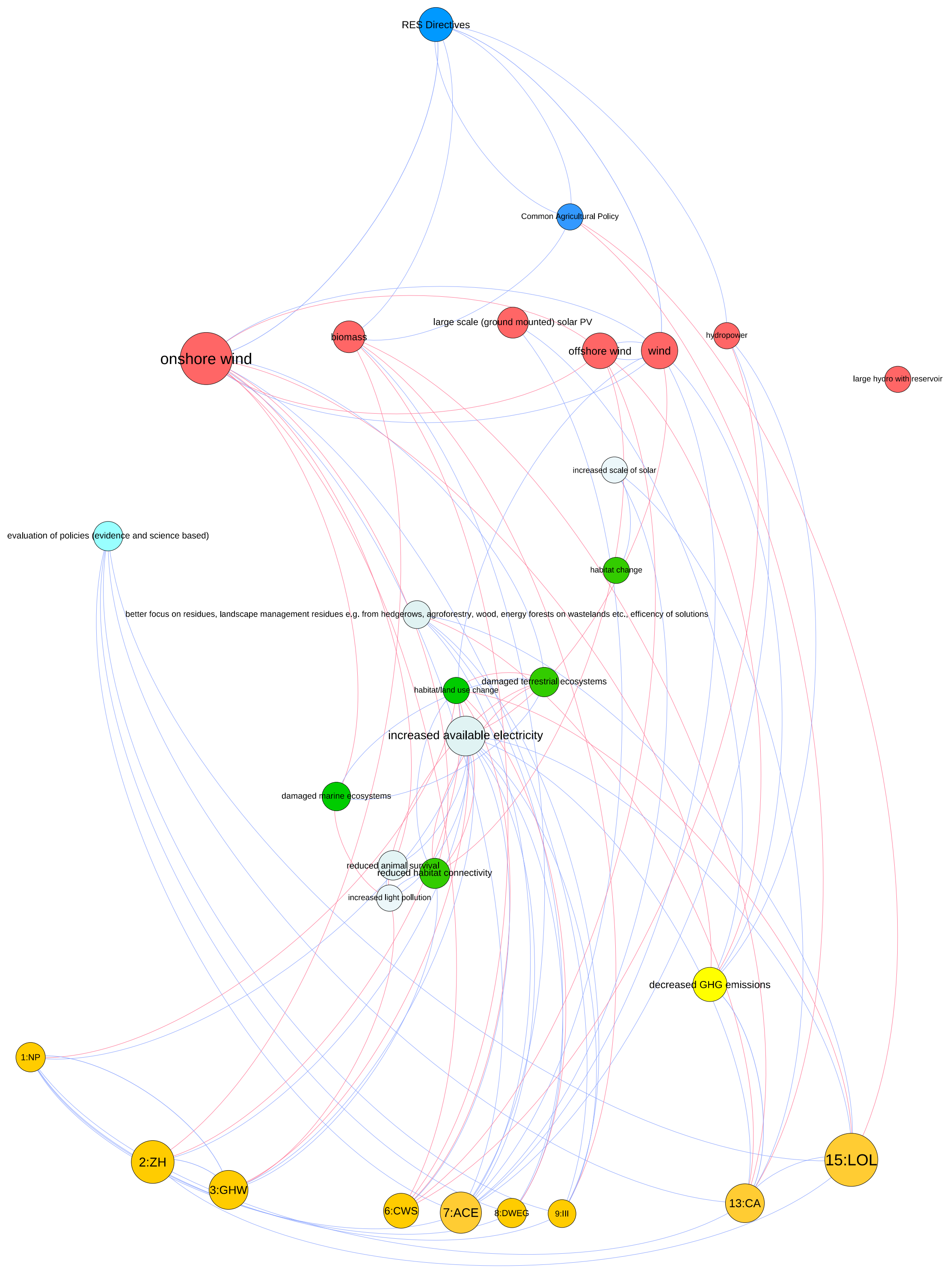

*Figure 5: Integrated m*odel of energy-biodiversity-SDGs interactions, displaying only nodes of degree at least 12 and their associated links, nodes sized by degree.

The integrated model was complex with a large number of both positive and negative interactions. Nodes are coloured according to their type: policies as blue, RES as red, biodiversity and human impacts as green or pink, and SDG impacts as orange. GHG emissions are yellow and decreased GHG emissions were key to many effects. Grey-green nodes are not categorised. Blue edges indicate positive impacts and red negative. This does not necessarily translate to a “good” or “bad” outcome, except in the case of final impacts on SDGs.

Reducing the minimum node degree to 12 (see Figure 5) retained only the most-connected nodes, i.e., those who are most embedded in the system. Key policies retained were the RES Directives and Common Agricultural Policy. Technologies were onshore wind, offshore wind, wind (general), biomass, ground-mounted solar PV and hydropower. Key SDGs were 1: NP, 2: ZH, 3: GHW, 4: CWS, 7: ACE, 8: DWEG, 9: III, 13: CA and 15: LOL. Biodiversity impacts were habitat and land use change, damaged terrestrial and marine ecosystems and reduced habitat connectivity. Intermediate processes were science and evidence-based policy evaluation, reduced GHG emissions, increased scale of solar, better focus on residues and solution efficiency, increased light pollution and reduced animal survival.

More model images are included in Appendix V.

Technologies

The technologies described were solar, wind, hydropower, bioenergy and geothermal. Solar was often described as solar PV, and the wind was sometimes discussed separately as onshore or offshore. Bioenergy was treated as biomass (sources sometimes specified) and biofuels (sometimes distinguishing between first and second/higher-generation biofuels). Hydropower was often treated separately from tidal/ocean energy and where these were specified separately this term is considered to refer to hydroelectric dams and reservoirs. Geothermal energy was only discussed by a small number of participants.

SDGs

All the SDGs were represented. 15: Life on Land, 7: Affordable and Clean Energy, and 13: Climate Action was the most connected SDGs. 5: Gender Equality and 17: PFG was the least connected. Impacts on 7: ACE were almost all positive. Impacts on 2: Zero Hunger and 15: Life on Land were strongly negative. Based on the number and signs of interactions (not taking strength into account), of the 17 SDGs, 10 were positively impacted, 6 negatively and 1 received no net impact (see Table 2).

Table 2: Impacts of RET on individual SDGs. ICSU-scaled impacts are obtained by multiplying the weight-summed impact by 3.

SDG	Total number of impacts on SDG	Number of positive impacts on SDG	Number of negative impacts on SDG	Net balance of numbers of positive and negative impacts	Overall weight-summed impact	ICSU-scaled weight-summed impact
1:NP	21	11	10	+	0.31	0.93
2:ZH	32	9	23	-	-0.49	-1.47
3:GHW	28	11	17	-	0.12	0.36
4:QE	6	6	0	+	0.23	0.69
5:GE	3	3	0	+	0.09	0.27
6:CWS	23	7	16	-	0.00	0
7:ACE	27	24	3	+	0.97	2.91
8:DWEG	14	11	3	+	0.28	0.84
9:III	12	7	5	+	0.11	0.33
10:RI	9	8	1	+	0.51	1.53
11:SCC	4	2	2	balanced	-0.01	-0.03
12:RCP	7	2	5	-	-0.18	-0.54
13:CA	25	13	12	+	0.35	1.05
14:LBW	9	3	6	+	-0.15	-0.45
15:LOL	44	18	26	-	-0.61	-1.83
16:PJSI	10	8	2	-	0.45	1.35
17:PFG	3	2	1	+	0.02	0.06

5.2 Findings and specific examples from the integrated model

5.2.1 Impacts on Humans

Several participants mentioned increased human displacement, increased employment opportunities, and decreased tourism/recreation as consequences of RES. One participant separated 1:NP into impacts associated with Europe or with developing countries, and this resulted in more positive impacts for Europe but more negative impacts for developing countries. The overall impact on 1:NP was positive (0.93). Participants considered that 2:ZH was strongly negatively impacted by RES (-1.47). The disproportionate impacts of RES on disadvantaged groups were noted by the participants. Overall, the loss of tropical and temperate croplands would negatively impact people in less-developed countries, affecting 1:NP and 2:ZH, as well as 3:GHW. Two participants mentioned that RES projects could lead to human displacement. Changes (increases) in food prices, land grabs and changes to employment may lead to more conflicts over resources. Waste technology and the emissions associated with technology production can also lead to human health impacts. However, positive impacts can include increased employment and innovation, and many participants identified positive impacts on 8:DWEG. Social acceptance of RES was also discussed, with solar considered more widely supported than biomass, wind, hydropower and geothermal.

5.2.2 Impacts on Biodiversity

Biodiversity impacts largely focussed on effects on land, which resulted in impacts on 15:LOL, but some also concerned 14:LBW. The impacts on 15:LOL were negative (26/44; -1.83), while those on 14:LBW were mixed (6/9 positive; -0.45). Negative impacts included decreased biodiversity (overall, terrestrial, marine, freshwater). Onshore wind power was associated with risks to birds and bats through collision, disturbance, and displacement, with similar effects of offshore wind on marine and migratory birds and mammals. Positive impacts might include habitat creation. In the case of hydropower, this could lead to increased fish populations, although there could be damage to downstream wildlife and habitat creation; for large-scale ground-based solar PV, this could benefit pollinators. However, birds and pollinators were also at risk of negative impacts from monocultures for biofuel production. Light and noise pollution were mentioned as possible negative effects on wildlife. One participant considered the complex largely negative ecological effects that can arise, including reduced dispersal, survival, and reproduction and trophic cascades.

5.2.3 Impacts of Policies

Policies included the RES Directives (differentiated in some cases), Biofuel Directive, ILUC Directive, Common Agricultural Policy, Water Framework Directive, nature conservation policies including the Birds Directive, Bern Convention, and Bonn Convention, and also development policy, social policy, a domestic policy such as the UK National Planning Policy Framework. Participants also referred to enabling or disabling contexts, such as policy implementation, the use of evidence-based policy approaches, measures to mitigate environmental damage, failure to implement management plans and appropriate oversight.

5.3 Case study insights

Selected case studies were created to describe particular aspects of the system. These are based on models which discussed them in detail, whether or not these were integrated into the final model, with the exception of human impacts, which was based on our literature review.

5.3.1 Impacts of biofuels

This is based on six individual participant models.

The RES targets specify that 20% of total energy must come from RES and 10% of energy for transport. The RED 10% Renewable Transport Target supports the production of both first- and second/higher-generation biofuels. The Biofuel Directive increases land used for feedstock for first-generation biofuels. The RED II Renewable Transport Target supports the production of second/higher-generation biofuels. The ILUC Directive sustainability criteria mitigate indirect land use change.

The RES targets and Biofuel Directive increase the demand for biofuels and hence their price. (One participant also mentioned the role of "perverse and harmful environmental subsidies for biomass and biofuel production.") This increases biofuel production in European, middle-income (developed) and less-developed countries. In all cases, this has effects on food production and nature. Increased biofuel demand leads to the production of biofuels including palm oil outside the EU and maize production inside the EU. Crop-based feedstock for bioenergy positively affects 7: ACE and biofuel production can boost 8: DWEG.

Biofuels other than those produced from municipal waste result in increased monocultures and decreased cropland for food production. Increased biofuel demand increases the production of food crops (biofuel). This increases both the cropland area and agricultural intensity. However, this decreases the land available for food crops (nutrition), which negatively impacts 2: ZH, as well as increasing deforestation both directly and through the decreased land available for food crops (nutrition). The higher demand for food crops (biofuel) also increases global food prices, decreasing their availability and thus negatively impacting global nutrition and food security (1: NP and 2: ZH). Impacts on food production are particularly negative in less-developed countries, which in turn negatively impacts 2: ZH, 8: DWEG and 16: PJSI. Increased agricultural intensity leads to water pollution through nutrient and chemical runoff (impacts on 6: CWS, 14: LBW). It also increases emissions of non-CO2 GHG and fossil-derived CO2, which leads to negative impacts on 13: CA.

The production of first-generation biofuels, such as palm oil, leads to indirect land use change. Increased cropland area damages natural habitats, particularly terrestrial ecosystems including forests, which impacts 15: LOL. This, in turn, leads to both higher emissions through land use change, and the loss of carbon benefits from the ecosystems that are replaced, which both increase global emissions and have negative impacts on 13: CA. Using the example of palm oil, production results in increased GHG emissions, both directly and indirectly via deforestation, and increases the risk of fires, thus impacting 3: GHW, as well as leading to soil subsidence and flooding. In general, deforestation also leads to species introduction and thus invasive species, and habitat change. Increased invasive species also increase habitat change. Increased monocultures damage terrestrial biodiversity (especially for pollinators and birds). Within the EU, maize production for biofuel increases GHG emissions and leads to the drainage of peatlands, resulting in soil subsidence and flooding, reduced water regulation, and increased fires. Peatland rewetting can mitigate the harmful effects of drainage.

5.3.2 Economic effects

This is based on three models which focussed on the economic context.

RES support through the RES Directives is the most straightforward policy approach affecting RES deployment. RES Directives increase demand for first-generation biofuels, which increases their price and drives further production. However, three additional avenues of thinking are important.

First, the interaction between RES support and the EU Emissions Trading Scheme. The latter also promotes the use of RES. However, RES support may drive down the ETS allowance price, reducing ETS incentives for RES deployment, in an example of "policy feedback", when a policy affects subsequent political processes. Here, because Member States get revenue from selling allowances from ETS, a low price increased their support for “volume management”, which was aimed at reducing the supply of allowances and therefore raising the price. Increased EU ETS carbon price supports RES. If economic growth accelerates as a consequence of the biofuels mandate, ETS prices will go up. At the same time, this policy interaction may imply that RES support may indirectly (through reducing allowances prices) lead to higher use of some fossil-fuelled technologies, which can lead to ecosystem impacts.

Second, the effects on fossil fuel prices. The RES target of 20% of total energy from RES and 10% of transport energy support RES electricity generation and research and innovation for RES while decreasing support for fossil fuel energy R&D. This leads to a decrease in the price of fossil fuel energy. This, in turn, has negative consequences for 13: CA. Decreases in the price of fossil fuel energy are also driven by the increase in energy productivity due to RES R&I. Decreased energy prices also boost aggregate energy demand. This feeds back into the RES targets, as the percentage mandate maps into different quantity targets depending on the aggregate energy demand. If energy prices drop, there is both a domestic increase in use, and emissions, and a potential global increase in emissions (leakage).

Third, it is important that policies other than RES are considered when it comes to mitigating any adverse impacts of RES deployment. Additional policies (social policy, pollution control/land use regulation) are also relevant. A policy mix may be more effective to solve sustainability trade-offs, compared to an approach relying only on (modifying/questioning) RES support schemes.

Further economic and SDG effects occur through potential increases in food prices, as described above. It should also be noted that RES could also lead to economic growth through boosting innovation, and the overall impact on 8: DWEG was positive.

Solar

This is based on two models focussing on large-scale solar PV (LSPV) installations. Both LSPV and roof-based solar PV result in decreased GHG emissions and thus have positive effects on 13: CA, as well as delivering 7: ACE. Increased deployment of large-scale solar PV is supported by RES Directive (2009/28/EC), the Water Framework Directive and domestic policies such as the UK National Planning Policy Framework.

Large-scale solar PV has positive and negative impacts. It leads to diversified, thriving agriculture, improved soil condition, habitat creation through seeding/planting new areas, increased pollinator abundance, reduced use of fertilisers and pesticides and improved groundwater and air quality, thus benefiting 3: GHW. It can lead to increased biodiversity and ecotone, with positive effects on 15: LOL. Thriving agriculture increases income diversity, and in the special case of double land use (agrophotovoltaic) systems, can benefit 2: ZH, which is also supported by improved groundwater quality. Increased income diversity supports 8: DWEG.

However, installing LSPV leads to habitat change, resulting in a reduced barrier effect and less area available for cropland and rangeland (temperate and tropical), and decrease rangeland productivity. Cropland productivity is affected complexly: it can be boosted through increased pollinators but decreased due to the reduced application of fertilisers and pesticides. Reduced agricultural inputs also improve 3: GHW and 6: CWS. It can improve water quality through reduced cropland and improved soil condition, leading to positive impacts on 3: GHW. However, reduced cropland has a disproportionate impact on the poor and damages the attainment of 1: NP and 2: ZH.

Large-scale solar PV also has environmental impacts; it leads to increased mining of raw materials, and thus the need for transport of these materials; this negatively impacts 3: GHW. It can also decrease the landscape/amenity value. This decreases land and property prices and damages the attainment of 1: NP. More infrastructure is needed, which has negative impacts on 9: III. Tourism and recreation can also be negatively affected, which in turn impacts 3: GHW.

A lack of oversight and governance can lead to failure to achieve positive benefits such as boosting biodiversity, through processes such as not adhering to management plans. This can lead to negative impacts on 9: III and 15: LOL (the latter is otherwise positively impacted through improved biodiversity and water quality). Austerity worsens any problems with oversight and governance.

5.3.3 Policy interactions

This was based on three models.

Many participants were aware of the policy context which affects the outcomes of RES on biodiversity and the SDGs. The interactions with the EU Emissions Trading Scheme are discussed above.

One participant also noted that the environmental goals of RES policies could sometimes trade off against those of nature conservation policies. As an example, the Birds and Habitats Directives and Natura 2000 network, as well as the Bonn Convention all conflict with the development of onshore and offshore wind. Their effects may also mitigate some of the negative environmental consequences of RES, such as reduced habitat connectivity. Some participants also noted that the Common Agricultural Policy supports biofuel and biomass production. Policy implementation and enforcement played a role in improving the environmental outcomes of RES, and the importance of science-based, effective policy development was also noted. The role of SDG 4: QE in helping to develop more effective policies, as an example, to focus on effective use of biomass residues, was also mentioned.

Further policy approaches can also mitigate environmental damage, such as local pollution control measures such as emission standards and taxes. Visual impacts can be ameliorated by land use regulations such as planning, zoning, protected areas, and taxes. The effect of agricultural intensification can be offset by support for sustainable approaches.

5.3.4 Human displacement/justice impacts

Since the 1940s, when the construction of large-scale dams and hydropower facilities boomed, more than 45,000 large-scale dams have been developed globally. Dam construction generally requires a large area to be flooded to create the artificial water reservoir that provides the required water storage and hydraulic head (height difference) to the hydroelectric facility. In many cases, the created reservoir submerged large regions that were previously inhabited and used for productive purposes. The World Bank estimates that nearly 60-80 million people have been displaced worldwide due to the reservoirs created by large dams [1, 2]. Displaced communities, thus, lose their homes and communities, while income-earning assets (e.g., fishing) are affected in a wider area. Accordingly, people who are displaced may experience unfair treatment by being offered an undervalued price for their property, while compensation does not consider the social and cultural value of their land [1]. Dam-induced displacement also involves the concepts of compensation, resettlement, and development. The Environmental critique has shifted from their physical to such adverse social impacts of hydropower dam construction [3]. The latter, if unaddressed, can be very serious.

Probably the most well-known case of displacement is the 22.5 GW mega-project of the Three Gorges dam [4] that resulted in 1.4 million people being displaced by the dam's construction (1994-2003), of which around 87 percent were rural people in China. More recently, hydropower development of the Mekong river in south-eastern Asia has resulted in controversy. Millions of people will be affected by the constructions on the lower Mekong, one of the last non-regulated rivers in the world [5]. Moreover, 1 million people depend and on its fisheries [6]. During its construction, the Saddle Dam on the Mekong River (Laos) collapsed in July 2018. The result was 40 confirmed casualties, at least 1000 missing and 6600 displaced. Large-scale dam planning needs, thus, to integrate existing ecosystem and human livelihood vulnerabilities [7] with potential risks, their impacts and climate change.

6 Conclusions

We used expert participant knowledge to construct a conceptual model of the system in which renewable energy technologies supported by EU policies lead to potential downstream biodiversity and SDG impacts. The process of construction was informed by an additional model based on a non-systematic literature review of the relevant scientific literature. This also provided a basis for comparison to the participant models, with broadly similar conclusions.

While our results are based on qualitative assessment of relative impacts, and should thus be treated with caution, they provide insight into complex interactions which are challenging to assess through quantitative approaches. The resulting integrated model has potential to be further developed as a means of understanding which system components should be targeted by policy to reduce RET impacts.

We conclude that EU renewable energy policies **can support staying within the safe zone in Europe while avoiding transgressing it elsewhere by incorporating telecoupling effects**. The 2030 Agenda puts into perspective the safe zone between the ceiling imposed by nature and the floor imposed by social equity; according to this, all countries are developing countries because they transgress either ceiling or floor.

In addition, the following key messages can be drawn from this report:

1. **There is an overall positive impact of EU RETs across all SDGs**, largely due to their positive impacts on decarbonisation. RETs are likely to have some negative environmental impacts in the short term, which must be set against their long-term positive effects (relative to the use of fossil fuels) through the reduction of GHG emissions and their impacts on ecosystems. It is also noted, however, that the GHG emissions associated with the development and running of RES should be factored into their overall impact. SDG 7: Affordable and Clean Energy and 15: Life on Land was considered to be the most affected by RETs, reflecting positive contributions of RETs to climate goals, and negative impacts on terrestrial biodiversity, respectively. Biodiversity impacts vary, but typically include land take (land use competition) and resulting habitat change/loss (and related wildlife loss) as well as different forms of pollution (air, noise, visual, heat, etc.). Workshop participants mentioned the collision of birds or bats with onshore and offshore wind installations.
2. **The biodiversity impacts of RES reflect complex interactions that are gradually becoming clearer through research.** Negative impacts on biodiversity were most often identified. However, in some cases, both positive and negative impacts occur, and some of these were highlighted in the workshop. For instance, pollinator populations may benefit from solar PV technology, but are damaged by monocultures for biofuel production; hydropower may support fish populations, but negatively affect downstream wildlife. The model highlights critical processes such as habitat change, which could be the focus of policy to reduce negative impacts.
3. **Understanding the interactions of economic and environmental policies is essential when evaluating alternative solutions and impacts**. The wider policy context includes the environmental effects of policies such as the Common Agricultural Policy and the Water Framework Directive, as well as

particular local contexts which can strongly affect EU policy implementation and interact synergistically or antagonistically.

4. **Best practices in RET installation should be pursued, such as careful choice of location and operation, to minimize environmental impacts.** Impacts vary with RET technology but also with installation design, location and size. Possible guidelines include utilizing low nature-value land, alternative and/or evolutionary approaches for the electricity and transport sectors, the orientation of solar PV panels (south vs. east-west), and higher-generation biofuels.
5. **The use of rare materials like metals and their disposal at the end of the system life cycle must be considered.** Technological breakthroughs have already resulted in decreased requirements for materials and energy in the manufacturing process. Increasing efforts to source rare metals through reclamation rather than mining, in keeping with the EU's circular economy ambitions, would further reduce the environmental impacts of RETs.
6. **A broader understanding in identifying winners & losers needs to be put into practice, in order to leave no one behind:** While EU energy policy can help to attain SDG 1: No Poverty in Europe, it might hinder this in developing countries, through mechanisms such as decreased food security (SDG 2: Zero Hunger), due to the loss of tropical and temperate croplands. Complex spillover effects must be assessed carefully, as reaching some RET targets can have perverse and contradictory impacts on SDGs. Disenfranchised groups are more likely to suffer from potential negative impacts such as the loss of agricultural land.

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Appendix I: Workshop Agenda

Monday 19 November – Day 1		
12:00-12:30	Participants' registration	
9:00-10.30	Discussion and revision	Group discussion session and opportunity to revise individual models
10:30-11:00	Coffee	
11:00-12:30	Discussion and revision	Continued group discussion session and opportunity to revise individual/group models
12:30-13:00	Wrap-up presentation	Short presentation outlining the findings of the day and next steps
13:00-14:00	Lunch & Drinks	

Tuesday 20 November – Day 2		
9:00-10.30	Discussion and revision	Group discussion session and opportunity to revise individual models
10:30-11:00	Coffee	
11:00-12:30	Discussion and revision	Continued group discussion session and opportunity to revise individual/group models
12:30-13:00	Wrap-up presentation	Short presentation outlining the findings of the day and next steps
13:00-14:00	Lunch & Drinks	

Appendix II: Workshop Participants

Participant	Institution
Lea Appulo	Wetlands International
Tom Clarkson	Carkson & Woods
Marianne Darbi	UFZ Helmholtz Centre for Environmental Research/EKLIPSE
Gregor Erbach	European Parliament, EPRS
Corrado di Maria	UEA Tyndall Centre
Miriam Grace	University of East Anglia/EKLIPSE
Cary Hendrickson	University of Rome La Sapienza
Reinhard Klenke	UFZ Helmholtz Centre for Environmental Research
Agata Klimkowska	Eco-Recover Ecosystem Restoration Advice
Ioannis Kougias	European Commission, Joint Research Centre
Paul Lehmann	MultiplEE, University of Leipzig & UFZ
Gerd Lupp	Technische Universität München
Alexis Meletiou	UFZ Helmholtz Centre for Environmental Research/EKLIPSE
Hannah Montag	Carkson & Woods
Brendan Moore	University of East Anglia
Leila Niamir	University of Twente
Myriam Pham-Truffert	Centre for Development & Environment, University of Bern
Zoltan Rakonczay	European Commission, DG for Research and Innovation
Pip Roddis	University of Leeds
Henri Rueff	Centre for Development & Environment, University of Bern
Marieke Sassen	World Conservation Monitoring Centre
Rania Spyropoulou	ATEPE Ecosystem Management Ltd
Thomas Tscheulin	University of the Aegean
Julia Wiehe	Leibniz Universität Hannover
Allan Watt	Centre for Ecology & Hydrology/EKLIPSE
Meseret Wondirad	German Federal Association for Sustainability

Appendix III: Biome classifications and coding

Workshop participants were asked to code impacts on biomes as outlined below. Natural biomes are classified after Olson et al 2001 and anthropogenic biomes after Ellis et al 2008.

Biome	Abbreviation
Terrestrial	
Deserts and xeric shrublands	DXS
Tropical and subtropical moist broadleaf forests	TMBF
Tropical and subtropical dry broadleaf forests	TDBF
Tropical and subtropical coniferous forests	TCF
Temperate broadleaf and mixed forests	TeBMF
Temperate coniferous forest	TeCF
Boreal forests / Taiga	BFT
Tropical and subtropical grasslands, savannas and shrublands	TSGSS
Temperate grasslands, savannas and shrublands	TeGSS
Flooded grasslands and savannas	FGS
Montane grasslands and shrublands	MGS
Tundra	T
Mediterranean forests, woodlands and scrubs	MFWS
Mangroves	M
Freshwater (please specify in addition one of tropical/subtropical or temperate)	
Large rivers	(T/Te)LR
Large river headwaters	(T/Te)LRH
Large river deltas	(T/Te)LRD
Small rivers	(T/Te)SR
Large lakes	(T/Te)LL
Small lakes	(T/Te)SL
Xeric basins	(T/Te)XB
Marine	
Polar	P
Temperate shelf and seas	TeSS
Temperate upwelling	TeU
Temperate coral	TeC
Tropical shelf and seas	TSS
Tropical upwellings	TU
Tropical coral	TC
Pelagic	P
Abyssal	A
Hadal	H

Anthropogenic	
Dense settlements	(T/Te)DS
Villages	(T/Te)V
Croplands	(T/Te)C
Rangelands	(T/Te)R

Appendix IV: Individual Models

This Appendix contains the models produced in Mental Modeler by each of the 19 workshop participants. Model elements are exactly as outlined by individual participants. Some models contain further text descriptions created for internal use while integrating the models.

1. Lea Appulo

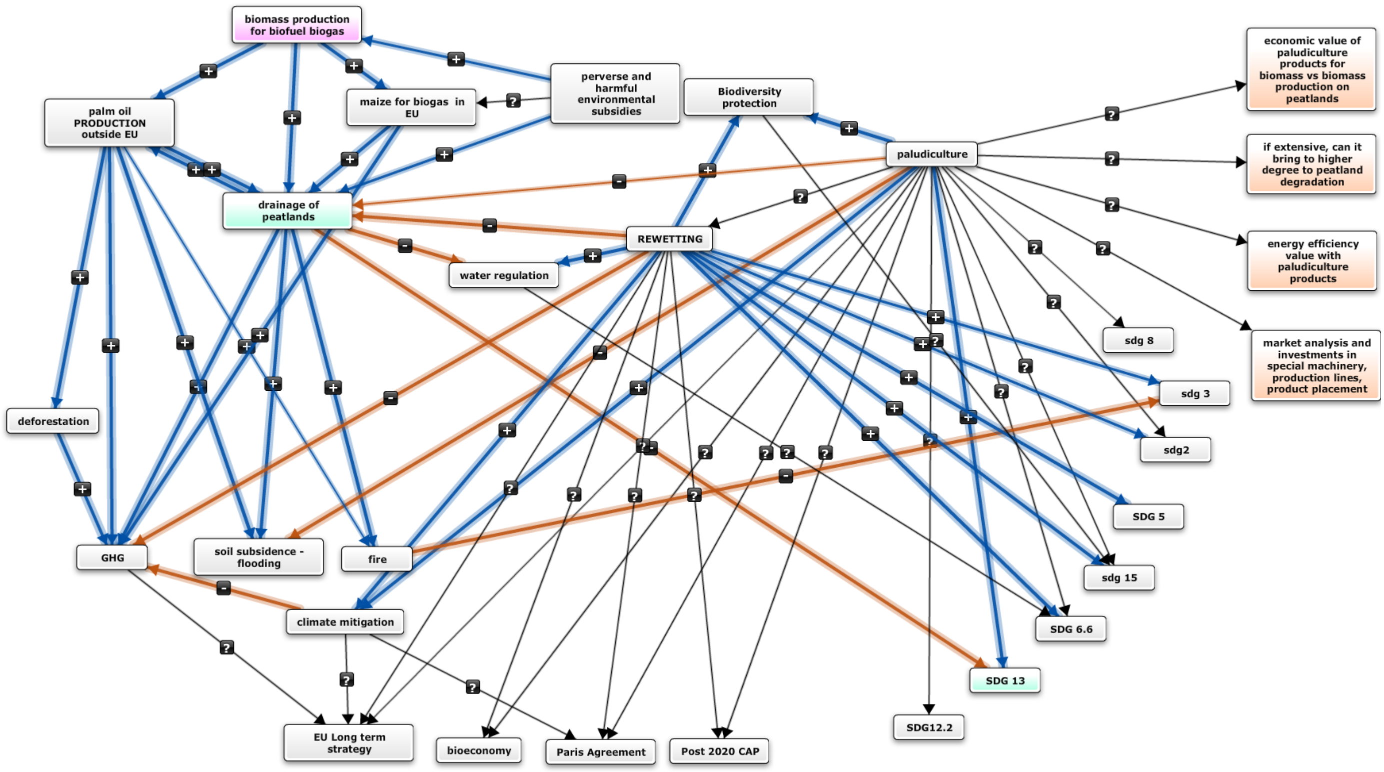

Figure 6: Model produced by Lea Appulo, focussing on peatland drainage for biofuels and biogas, which can be combatted by paludiculture and rewetting. The biofuels are palm oil outside the EU and maize within the EU.

Policy	Technology	Biodiversity	SDG
EU long-term	Biofuels (palm oil)	Drainage of peatlands	2
strategy	Biogas (maize)		3
Paris Agreement			5
Post-2020 CAP			6.6
Perverse			8
environmental			12.2
subsidies			13
			15

2. Tom Clarkson

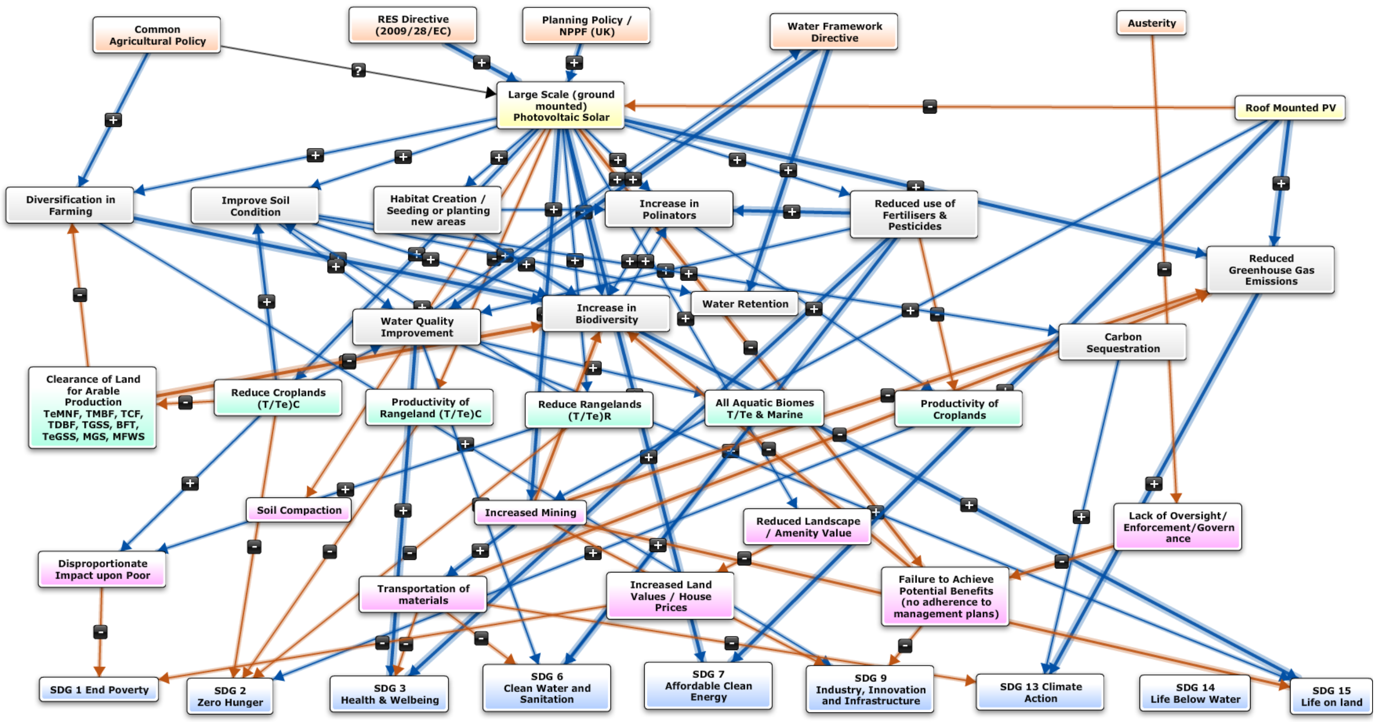

Figure 7: Model produced by Tom Clarkson, focussing on large-scale and roof-mounted solar PV.

Policy	Technology	Biodiversity	SDG
RES Directive 2009	Large-scale (ground-mounted photovoltaic solar)	Diversification in farming	1
Common Agricultural Policy		Improved soil condition	2
Water Framework Directive		Habitat creation	3
UK Planning Policy/National Planning Policy Framework		Increase in pollinators	6
Austerity		Increase in biodiversity	7
		Reduced croplands	9
		Reduced rangelands	13
		Improved aquatic biomes (T/Te, marine)	14
			15

3. Gregor Erbach

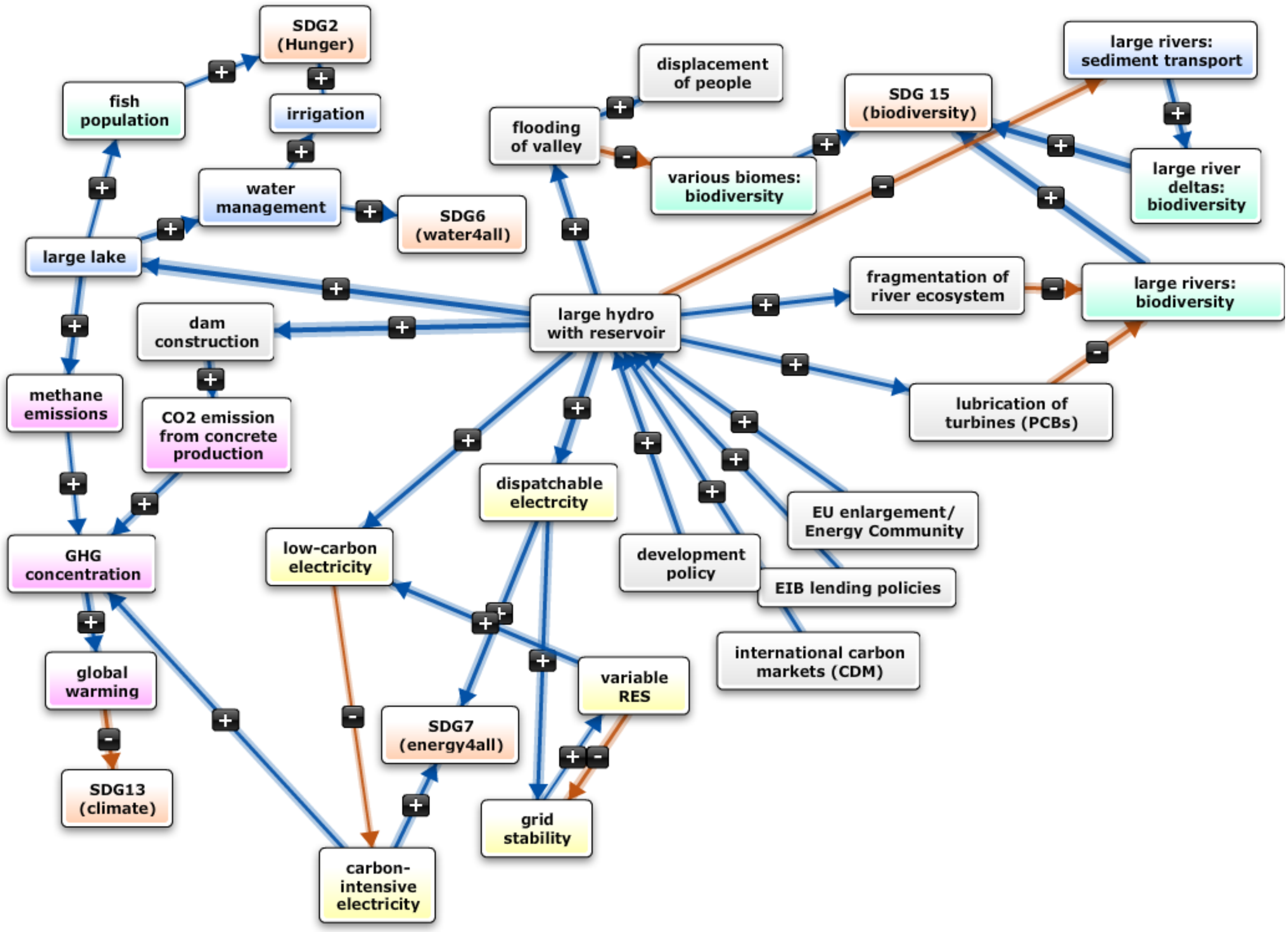

Figure 8: Model produced by Gregor Erbach, focussing on the impacts of large hydropower, including differentiating biodiversity impacts on large rivers and large river deltas.

Policy	Technology	Biodiversity	SDG
EU enlargement/energy community **EIB lending policies** **International carbon markets** **Development policy**	Large hydropower	Increased fish population Negative impacts of flooding valleys Negative impacts on large river ecosystems due to fragmentation and PCBs Positive impacts on large river biodiversity through reduced sediment transport	2 6 7 13 15

4. Cary Hendrickson

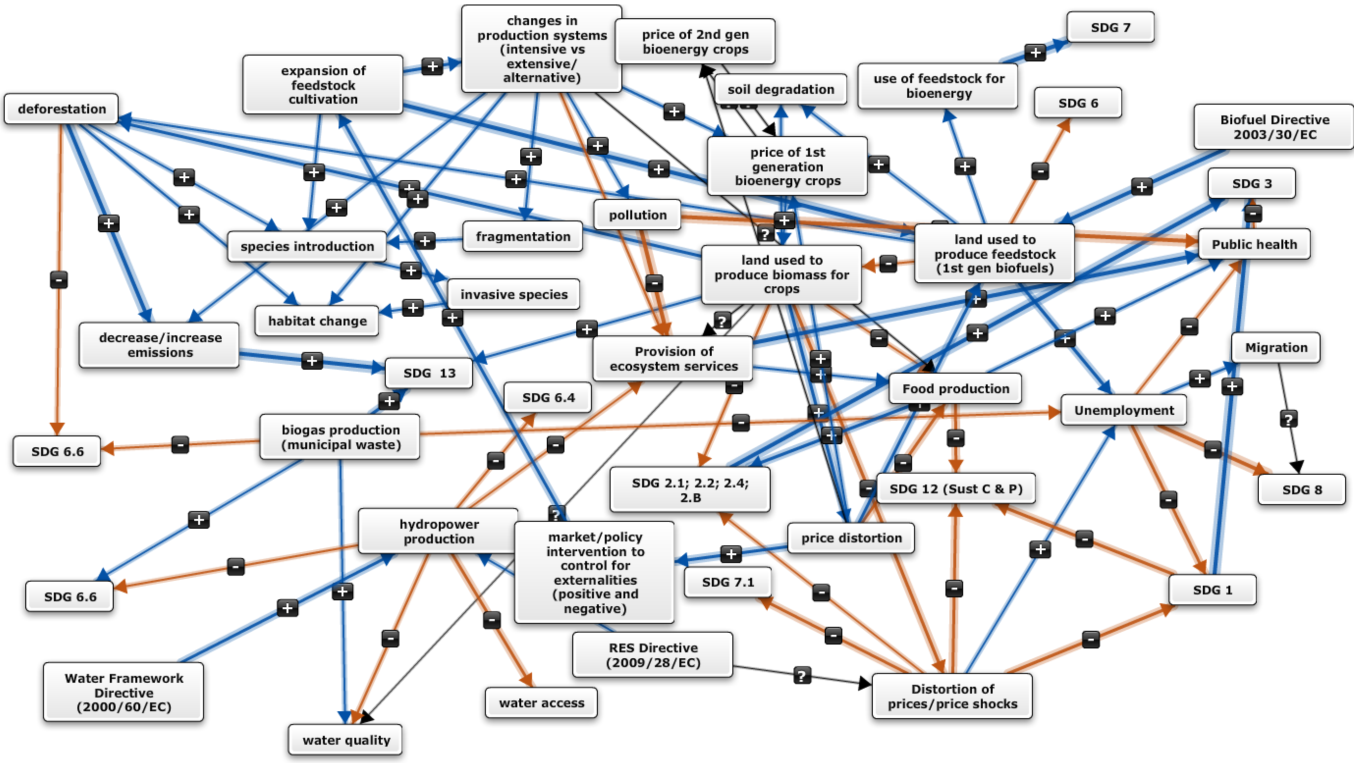

Figure 9: Model produced by Cary Hendrickson, focussing on bioenergy from crops and biofuel from municipal waste.

Policy	Technology	Biodiversity	SDG
RES 2009	Biofuels (1st generation)	Deforestation	1
Water Framework Directive	Biofuels (2nd generation)	Habitat change	2
Biofuel Directive	Biomass from municipal waste	Provision of ecosystem services	3
		Invasive species/species introduction	6
		Soil degradation	7
		[Habitat] fragmentation	8
			12
			13

5. Reinhard Klenke

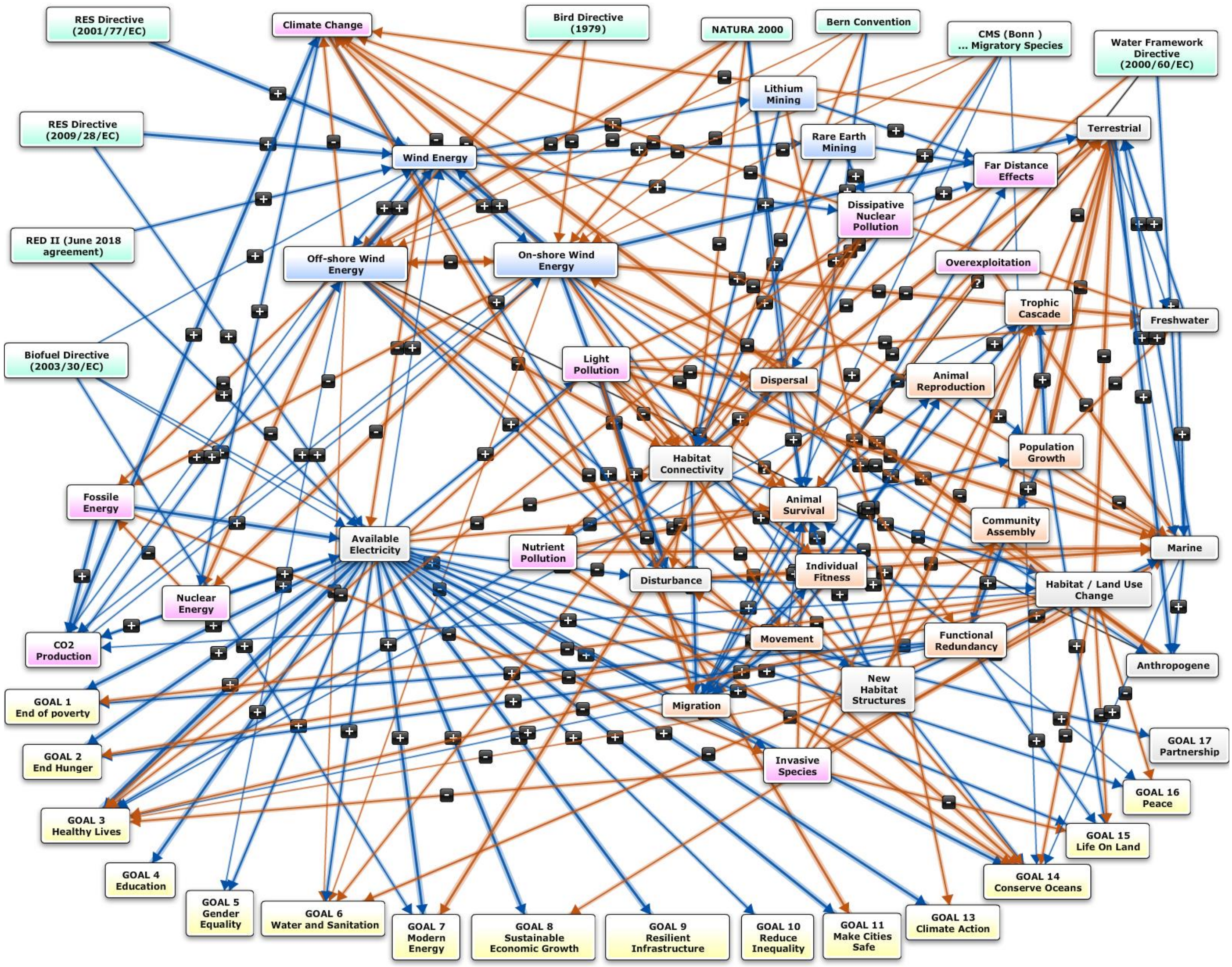

Figure 10: Model produced by Reinhard Klenke, focussing on wind energy.

Policy	Technology	Biodiversity	SDG
RES 2001	Wind	Invasive species	1
RES 2009	Offshore wind	New habitat structures	2
RED II	Onshore wind	Disturbance	3
Biofuel Directive		Animal survival	4
		Individual fitness	5
		Animal reproduction	6
		Community assembly	7
		Dispersal	8
		Habitat/land use change	9
		Migration	10

		Trophic cascade	11
		Population growth	13
		Habitat connectivity	14
			15
			16
			17

6. Agata Klimkowska

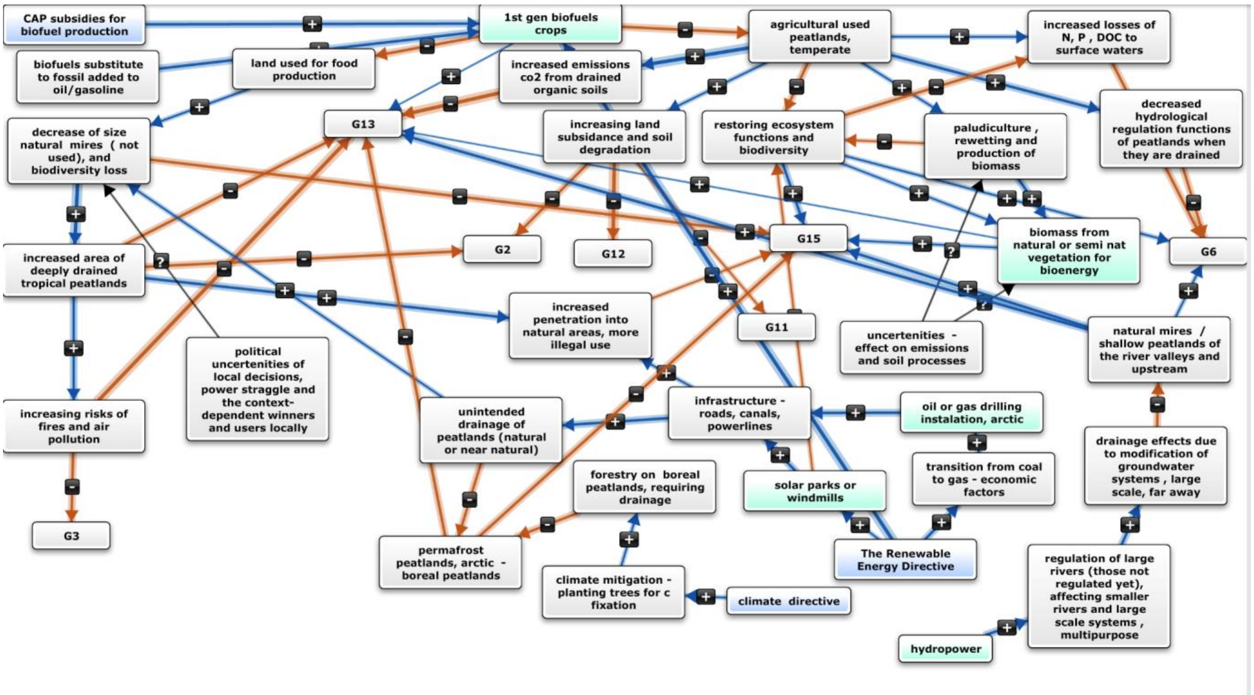

Figure 11: Model produced by Agata Klimkowska, focussing on peatlands, 1st generation biofuels, biomass, solar, hydropower and oil or gas.

Policy	Technology	Biodiversity	SDG
Renewable Energy	1st gen biofuels	Agricultural temperate	2
Directive	biomass	peatlands	3
	oil or gas		5
CAP subsidies for	solar	Permafrost peatlands,	6
biofuel production	hydropower	boreal peatlands	11
(crops)			12
		Deeply drained tropical	13
Climate directive (?)		peatlands	15
		Land used for food	
		production	

7. Ioannis Kougias

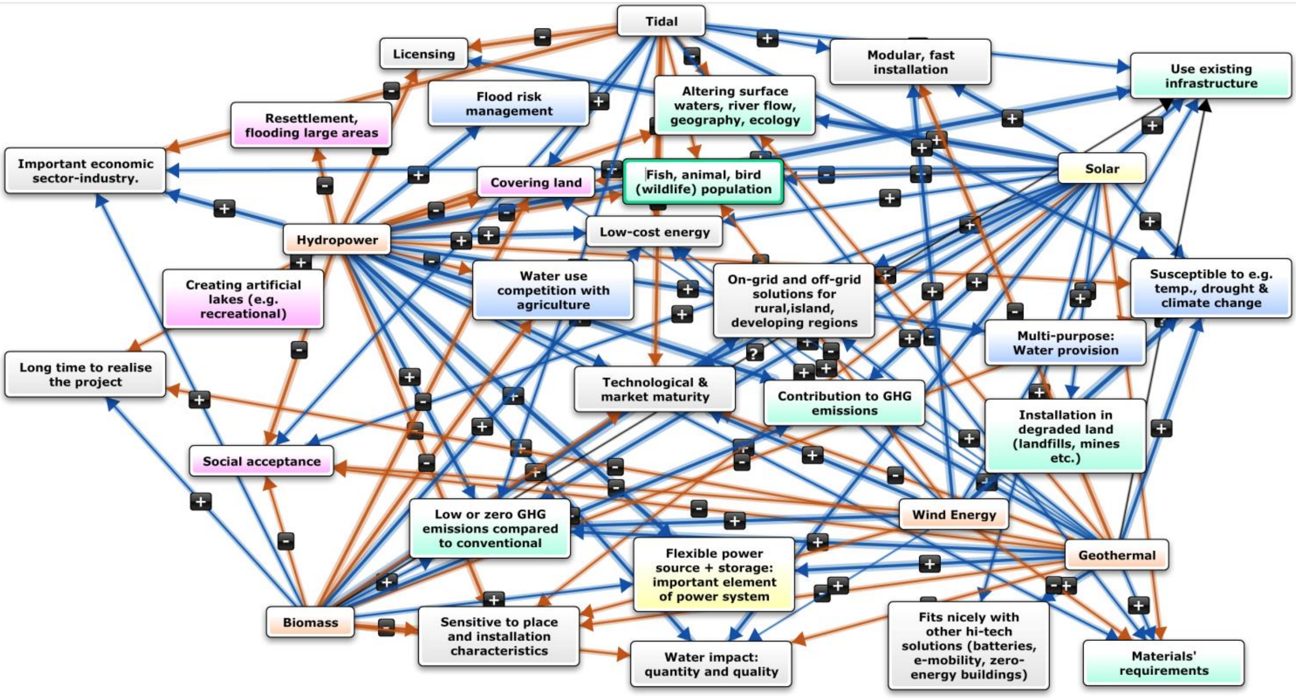

Figure 12: Model produced by Ioannis Kougias, focussing on hydropower, biomass, tidal, solar, wind and geothermal, exploring the logistical advantages and disadvantages of these.

Hydropower is low-cost and has reduced GHG emissions compared to conventional energy sources. It can make a positive contribution to economic development and can improve water quantity and quality, and contribute to flooding management. It offers flexibility in power production and storage, has reached technological, and market maturity. It can have a positive effect on recreation through the establishment of artificial lakes. It also has negative impacts, including the need for resettling people due to flooding large areas of land, can cover land, and can damage wildlife populations. Water use can lead to competition with agriculture. It takes a long time to implement a project, and licencing is required. It is sensitive to place and installation characteristics. There is a lack of wide social acceptance.

Example: solar energy can use existing infrastructure, be installed on degraded land, as modular, fast installation, fits well with other hi-tech solutions such as batteries, e-mobility, and zero-energy buildings. It can provide on-grid and off-grid solutions for rural, island and developing regions. It offers strong reductions in GHG emissions and wide social acceptance. However, it covers land, is susceptible to drought and climate change, and sensitive to place and installation characteristics.

Policy	Technology	Biodiversity	SDG
	Solar Hydropower Tidal Biomass Wind geothermal	Animal populations Surface waters, river flow, geography, ecology	

8. Paul Lehmann

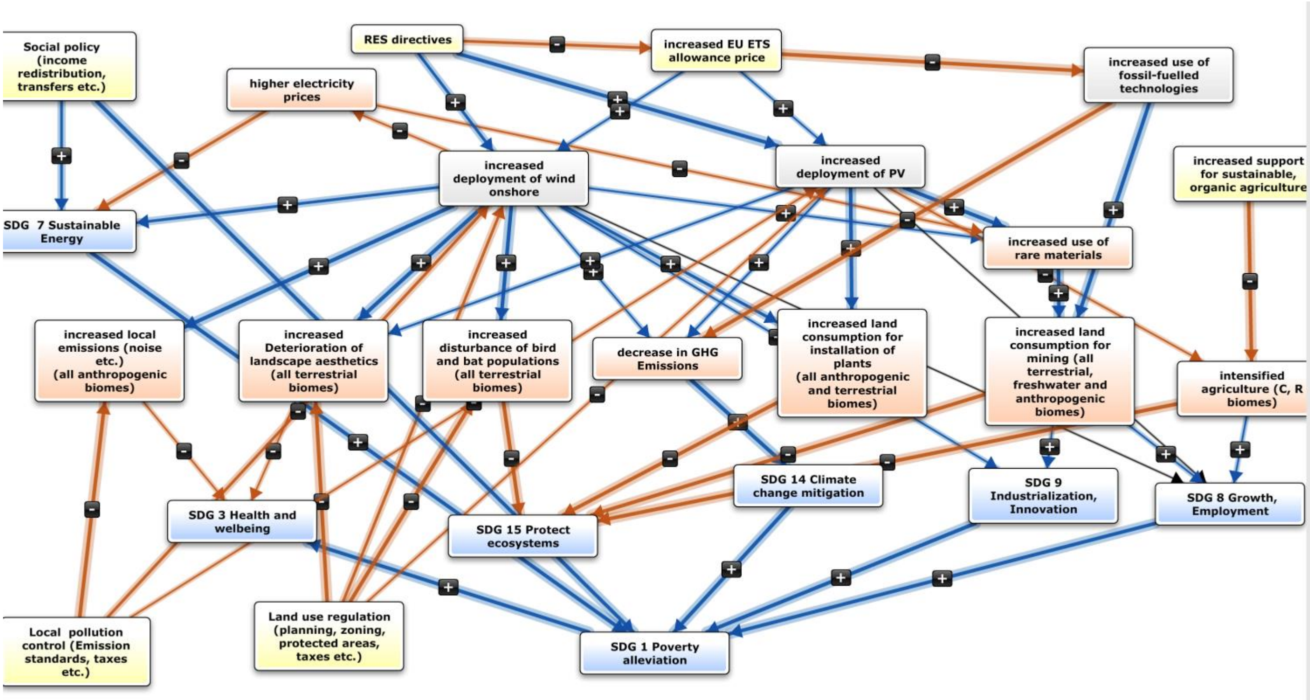

Figure 13: Model produced by Paul Lehmann, focussing on onshore wind and solar PV.

It incorporates some of the measures that can help to control negative RE impacts. SDG 13 appears to have been accidentally listed as 14.

Policy	Technology	Biodiversity	SDG
RES	Onshore wind	Disturbance of bats and	1
Social policies	Solar PV	birds (all terrestrial	3
EU ETS		biomes)	7
Local pollution		Local emissions (all	8
control		anthropogenic biomes)	9
Land use regulation		Land footprint	14
		Mining	15
		Intensified agriculture	
		Deterioration of	
		landscape aesthetics	

9. Gerd Lupp

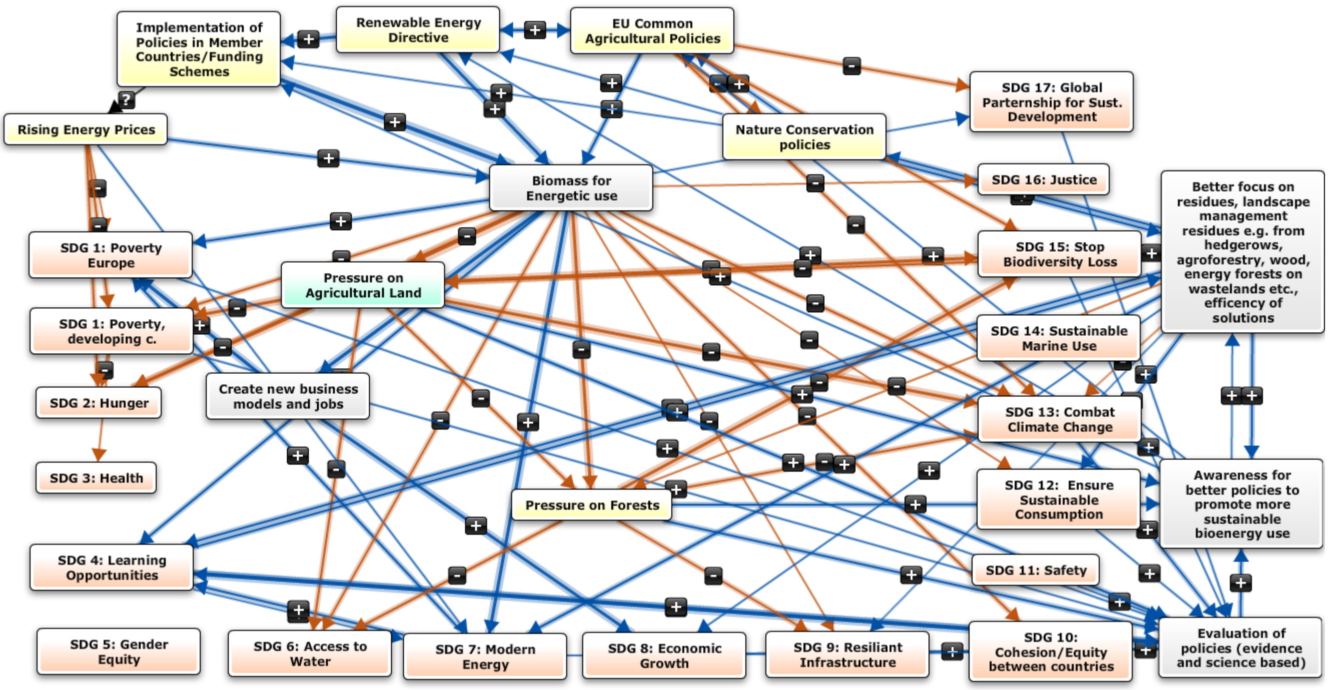

Figure 14: Model produced by Gerd Lupp, focussing on biomass for energy.

Policy	Technology	Biodiversity	SDG
RED	Biomass	Pressure on agricultural land	1
CAP			2
Nature conservation policies		Pressure on forests	3
			4
			6
			7
			8
			9
			10
			11
			12
			13
			14
			15
			16
			17

10. Corrado di Maria

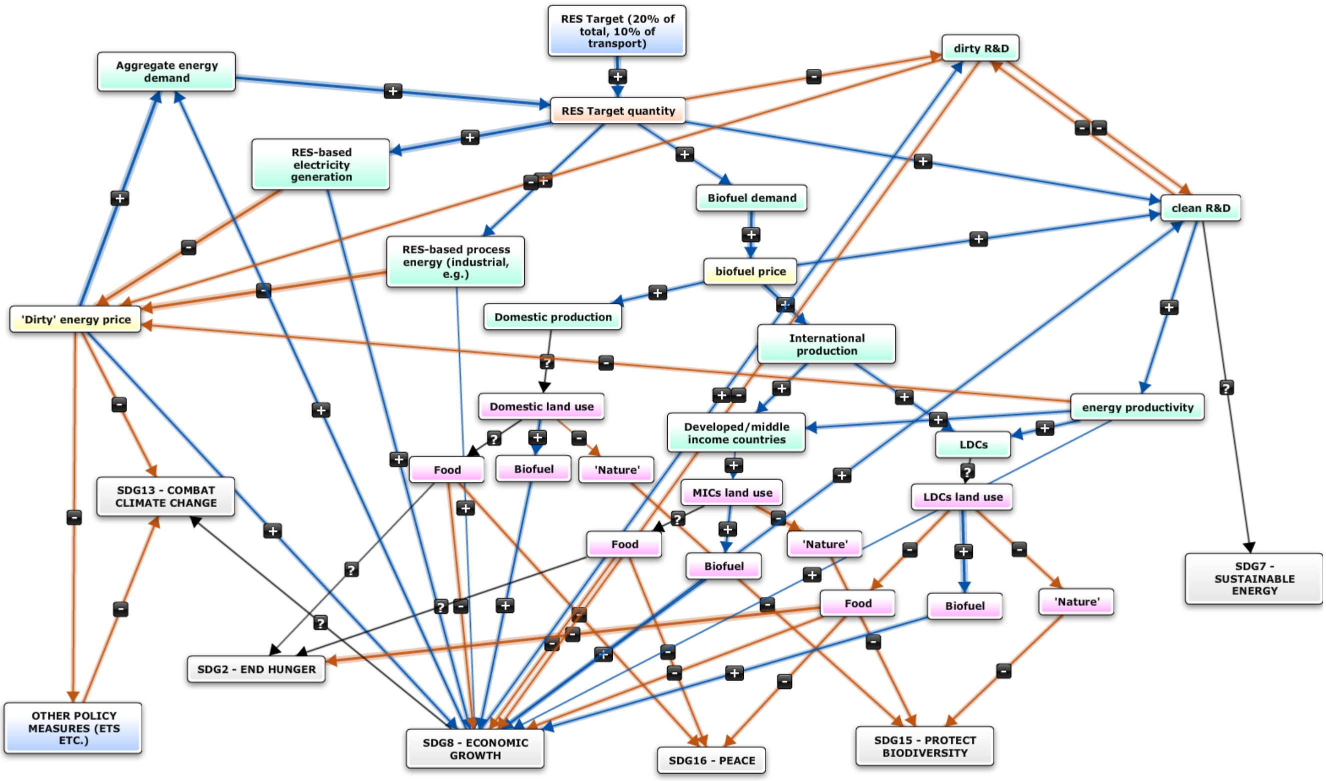

Figure 15: Model produced by Corrado di Maria, focussing on the economic factors that affect the impact of renewable energy use on the environment and SDGs.

This model differentiates domestic, developed/middle-income countries and less developed countries. It does not discriminate between different renewable energy sources.

Clean energy R&D helps to meet SDG7 and increases energy productivity, which decreases the price of fossil fuel-based energy. RES targets also increase RES-based electricity generation, which reduces the price of fossil fuel-based energy. These lower prices damage meeting SDG13. RES targets for biofuel increase the demand for biofuel, which increases biofuel price, increasing domestic and international production. Higher domestic production of biofuels affects domestic land use for food, biofuel, and nature. Higher international production of biofuels affects land use in middle-income and less developed countries, for food, biofuel, and nature. This has negative impacts on nature, damaging SDG15. In LDCs, land use changes negatively impact food provision, damaging SDG2, and SDG16. The impacts on SDG8 are complex: positively impacted by lower dirty energy price, RES-based electricity generation, RES-based process energy (industrial, etc.), biofuel production, clean R&D, energy productivity; negatively impacted by land use for food, dirty R&D. Domestic and MIC land use for food has unknown impacts on SDG2. SDG8 has unknown impacts on SDG13. Clean R&D has unknown impacts on SDG7.

Policy	Technology	Biodiversity	SDG
RES			2
			7
			8
			13
			15
			16

11. Hannah Montag

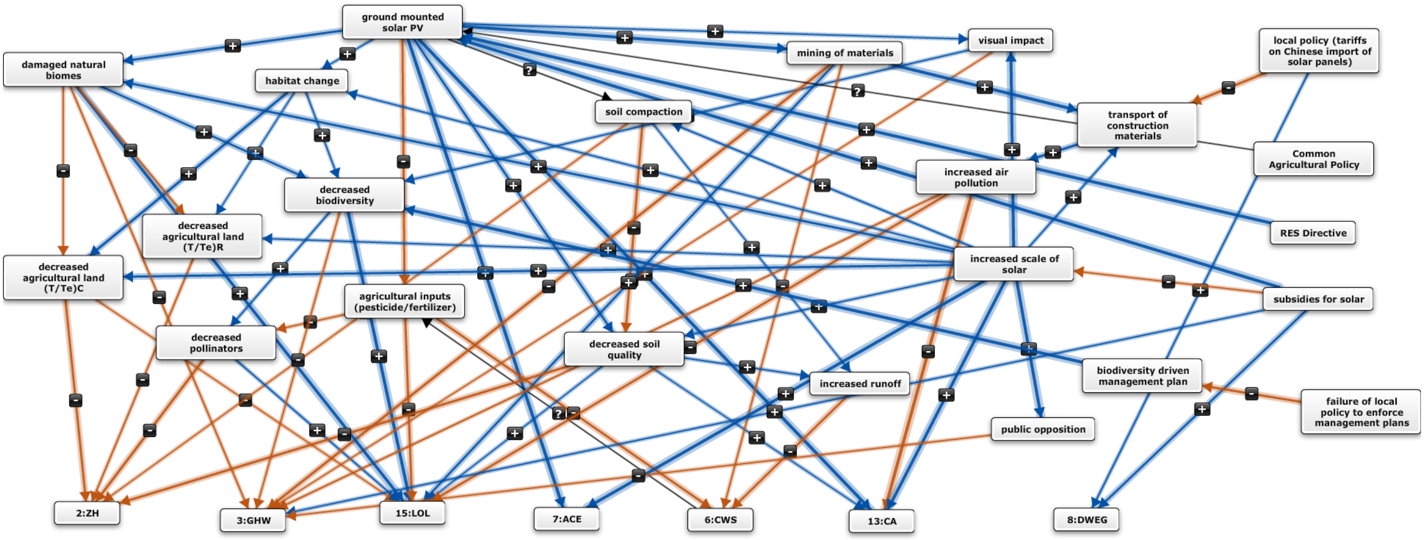

Figure 16: Model produced by Hannah Montag, focussing on ground-mounted solar PV.

Policy	Technology	Biodiversity	SDG
RES	Ground-mounted solar PV	Decreased pollinators Decreased biodiversity Habitat change Damaged natural biomes Decreased agricultural land (T/Te)C/R Decreased soil quality Increased air pollution	2 3 6 7 8 13 15

12. Brendan Moore

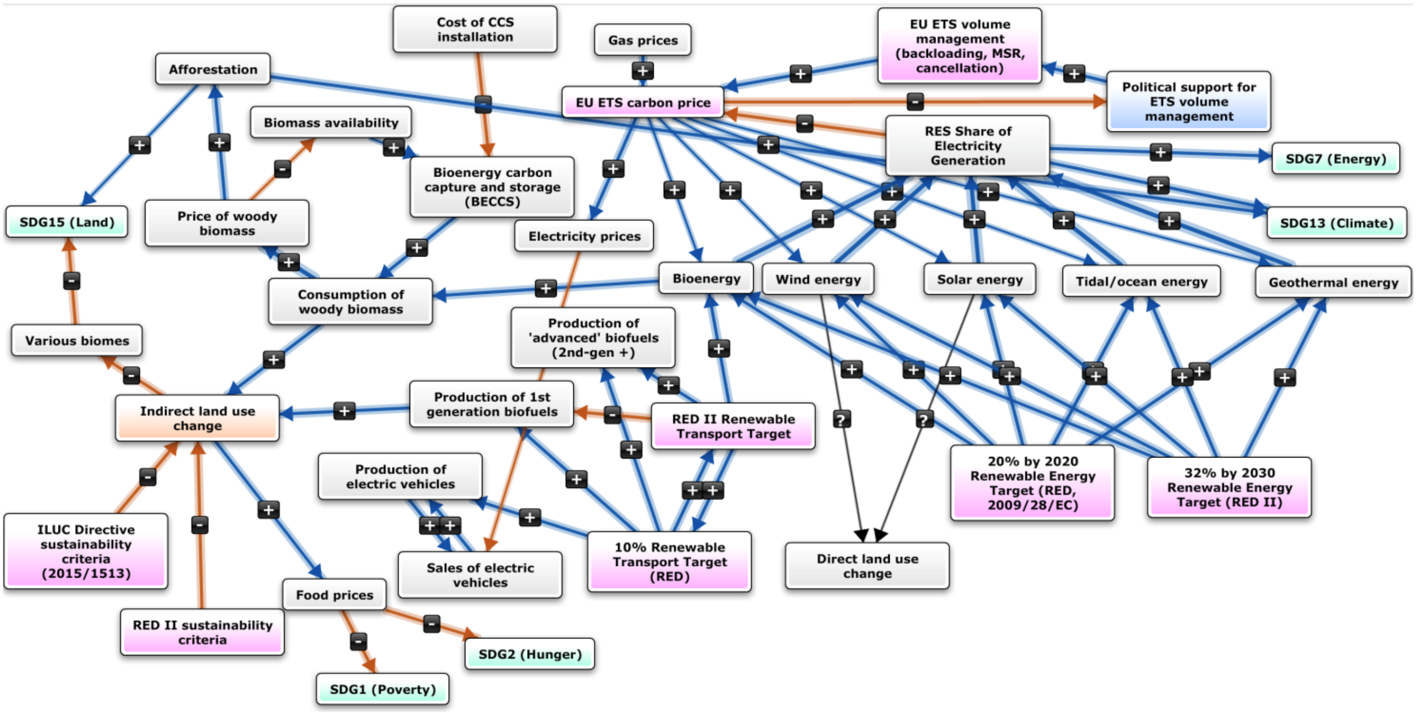

Figure 17: Model produced by Brendan Moore, focussing on first- and higher-generation biofuels, woody biomass, wind, solar, tidal/ocean, and geothermal energy.

Policy	Technology	Biodiversity	SDG
RED II sustainability	Wind	Indirect land use change	1
criteria	Solar	impacting various	2
RED RTT	Bioenergy	biomes	7
EU ETS carbon price	Tidal/ocean Geothermal	Afforestation	13
EU ETS volume			15
management			

Production of first-generation biofuels leads to indirect land use change (ILUC) with negative impacts on various biomes and thus negative impacts on SDG15. ILUC increases food prices with negative impacts on SDG1 and 2. The ILUC Directive decreases ILUC. RES share of electricity generation has positive effects on SDG7 and 13. It is fed by bioenergy, wind, solar, and geothermal energy. Bioenergy increases the consumption of woody biomass and thus its price, leading to afforestation and positive impacts on SDG15. It also decreases biomass availability, leading to bioenergy carbon capture and storage. Wind and solar energy have unknown impacts on direct land use change.

13. Leila Niamir

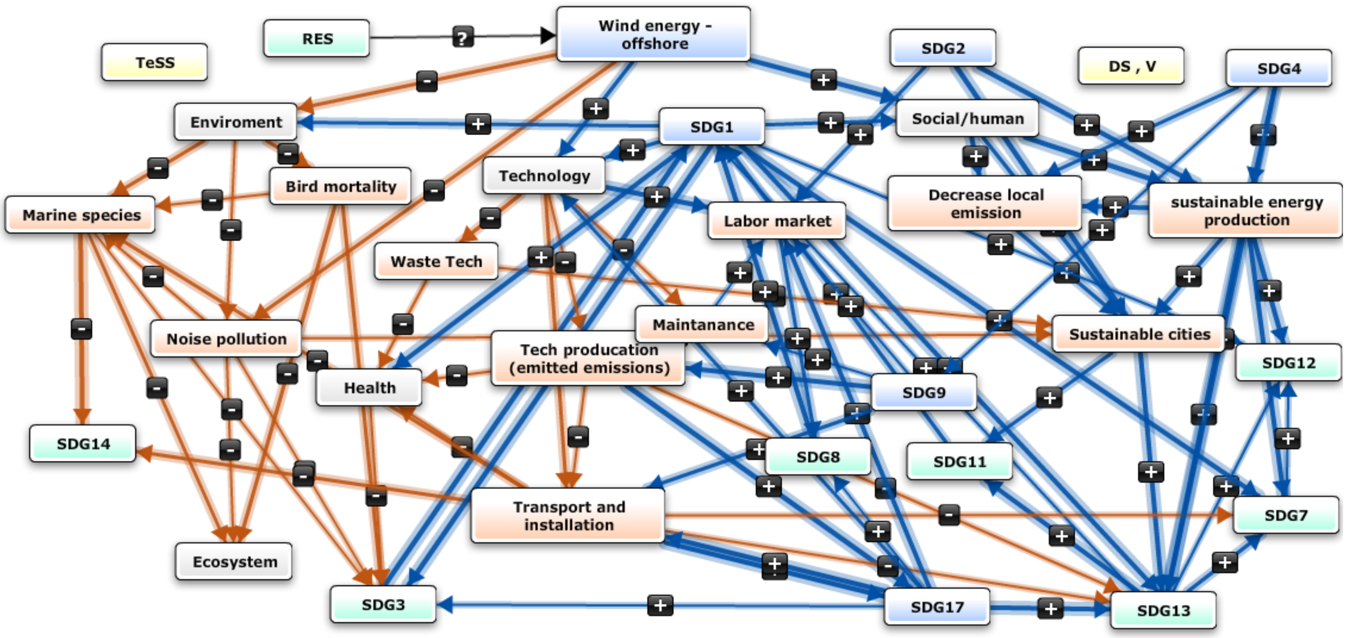

Figure 18: Model produced by Leila Niamir, focussing on offshore wind.

Offshore wind energy has positive impacts on social/human, increasing sustainable energy production thus decreasing local emissions. Both the latter improve cities' sustainability, which has a positive effect on SDG11, 12 and 13. Wind energy has a positive effect on technology, which leads to the production of waste tech, which has a negative impact on health, thus damaging SDG3. Waste tech also has a negative impact on cities' sustainability. Wind energy has a negative impact on the environment through bird mortality, marine species, and noise pollution, these, in turn, impact the ecosystem. Negative impacts on marine species lead to negative impacts on SDG14. Increased bird mortality negatively impacts SDG3. Technology has a negative impact on transport and installation, which in turn has a negative impact on SDG14. Technology has a negative impact on tech production (emitted emissions) which negatively impacts transport and installation; this, in turn, has a negative impact on health. Technology has a positive effect on the labour market, which has a positive impact on SDG8.

Policy	Technology	Biodiversity	SDG
RES	Wind energy (offshore)	Bird mortality	1
		Marine species	2
		Ecosystem	3
		Environment	4
			7
			8
			9
			11
			13
			14
			17

14. Pip Roddis

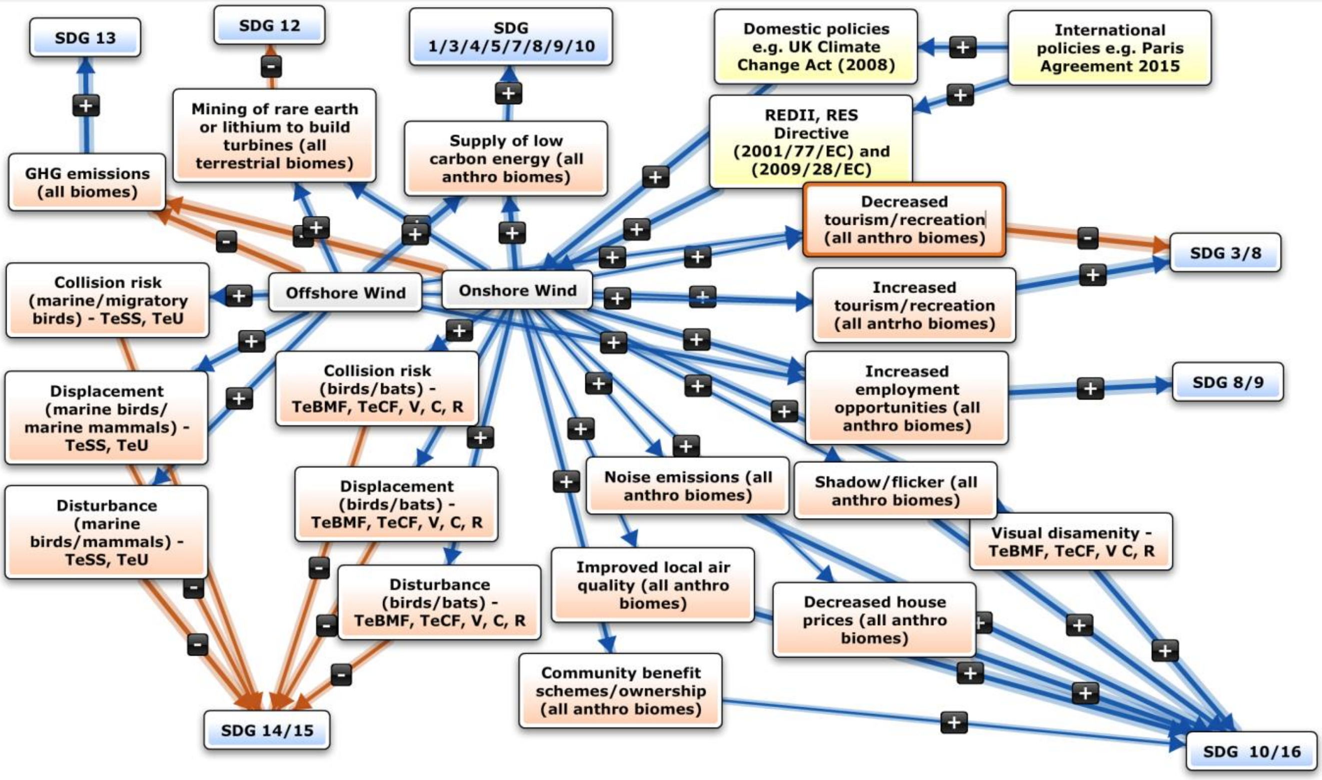

Figure 19: Model produced by Pip Roddis, focussing on onshore and offshore wind.

Onshore wind is supported by domestic policies, RES Directive 2001 and RED II, which are supported by international policies. Onshore wind leads to collision risk, displacement, and disturbance for birds and bats. Offshore wind leads to collision risk, displacement, and disturbance for marine birds and mammals; also collision risk for migratory birds. These biodiversity impacts damage SDGs 14 and 15. Both onshore and offshore wind reduce GHG emissions, which has positive impacts on SDG13. They improve the supply of low-carbon energy which is positive for all anthropogenic biomes and thus has positive impacts on SDGs 1,3,4,5,7,8,9,10. Onshore wind increases noise, which decreases house prices. Onshore wind improves local air quality and supports community benefit schemes/ownership. Onshore wind increases shadow/flicker, which leads to visual disamenity. Onshore wind increases employment opportunities and can both increase and decrease tourism and recreation. Onshore and offshore wind increase the mining of rare earth metals or lithium for turbine construction, which damages SDG12.

Policy	Technology	Biodiversity	SDG
International policies	Onshore wind	Collision risk,	3
Domestic policies	Offshore wind	displacement, and	7
RED I and II		disturbance (birds, bats,	8
		marine mammals)	9
		Mining for rare earth	10
		metals or lithium	13
		GHG emissions	15
			16

15. Marieke Sassen

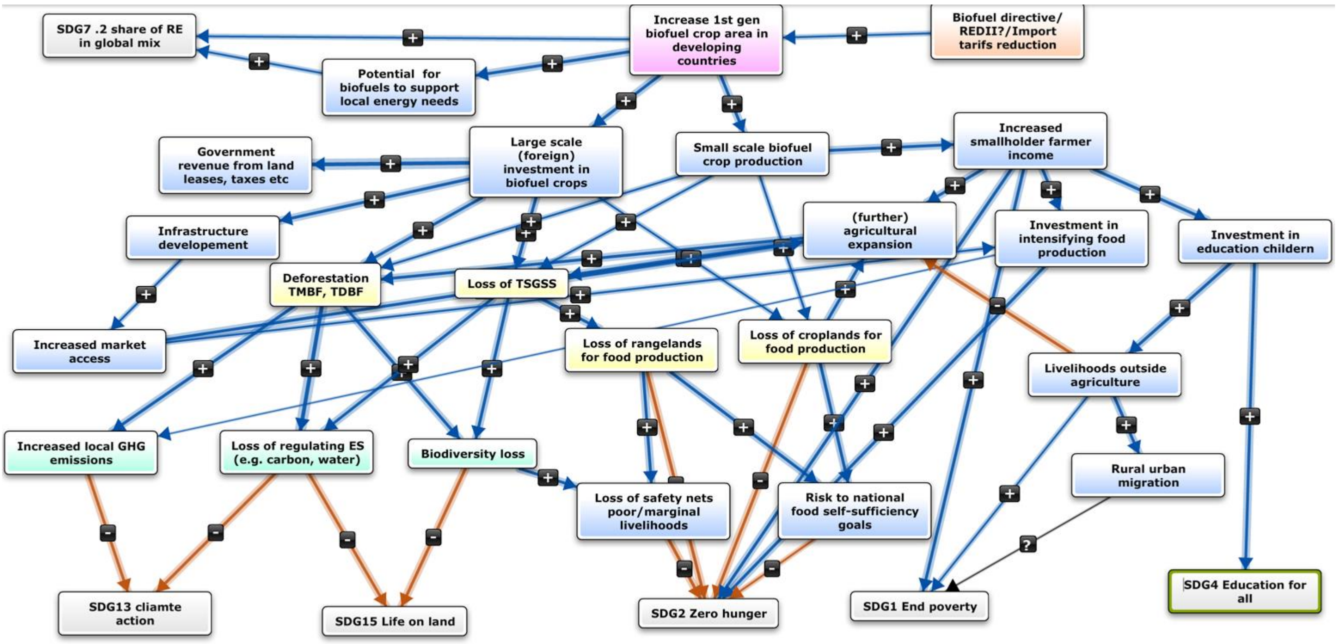

Figure 20: Model produced by Marieke Sassen, focussing on biofuels and their impact on agriculture, food security and socioeconomic aspects.

Policy	Technology	Biodiversity	SDG
Biofuel Directive **RED II** **Import tariff reduction**	Biofuel (crops)	Deforestation (TMBF, TDBF) Loss of TSGSS Loss of rangelands (food production) Loss of croplands (food production) Biodiversity loss Loss of regulating ES (e.g., carbon, water)	1 2 4 7 13 15

16. Thomas Tscheulin

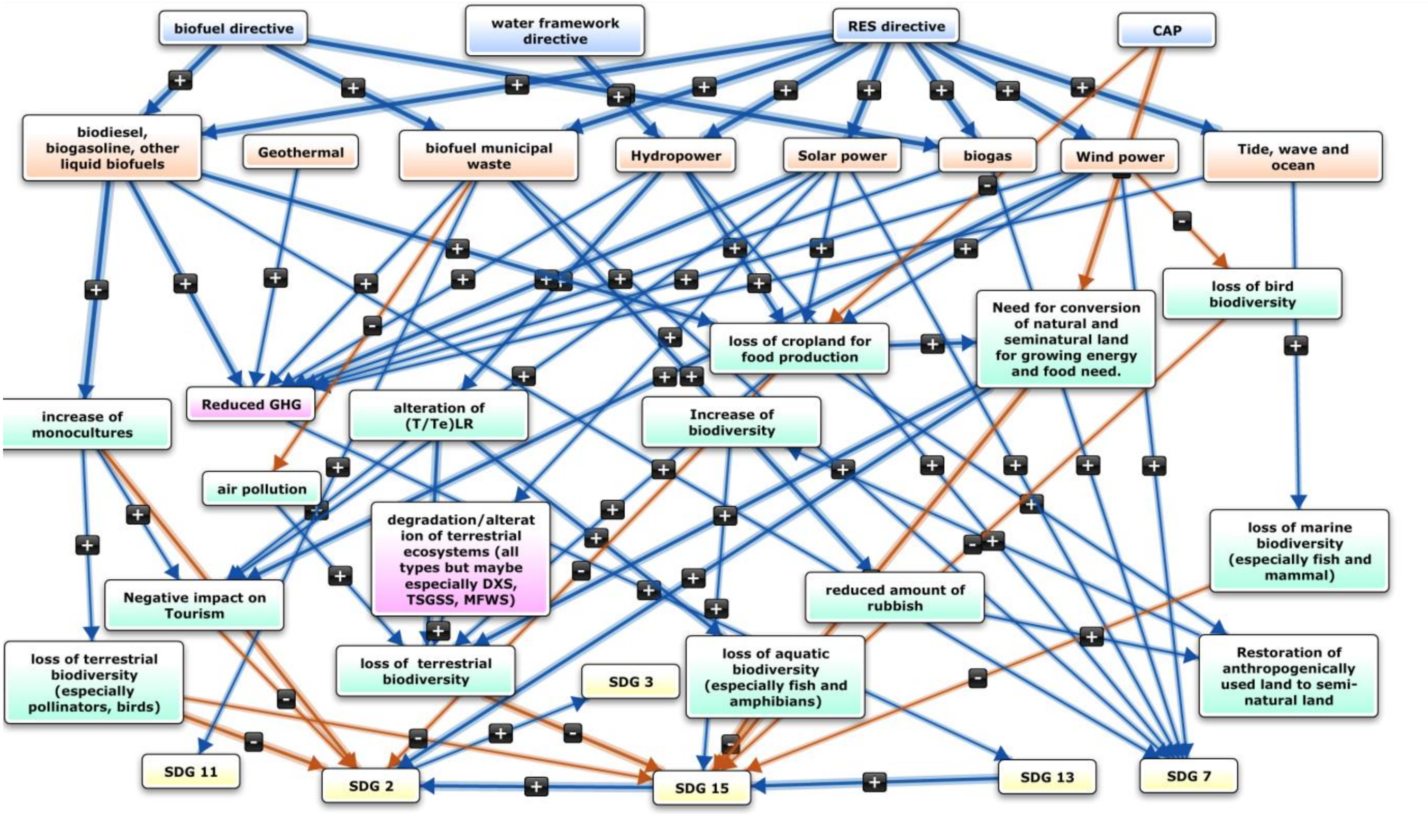

Figure 21: Model produced by Thomas Tscheulin, focussing on biodiesel, biogasoline, other liquid biofuels; geothermal; municipal biofuel waste; hydropower; solar power; biogas; wind; tide, wave, and ocean energy.

Policy	Technology	Biodiversity	SDG
RED	Biodiesel, biogasoline, other liquid biofuels	Loss of natural and seminatural land	2
Water Framework Directive	Geothermal	Loss of aquatic biodiversity	3
Biofuel Directive	Biofuel municipal waste	Loss of terrestrial biodiversity	7
	Hydropower	Loss of marine biodiversity	11
	Solar power	Restoration of anthropogenically used land to semi-natural land	13
	Biogas	Degradation/alteration of terrestrial ecosystems (all types but maybe esp. DXS, TSGSS, MFWS)	15
	Wind	Alteration of T/Te LR	
	Tide, wave, and ocean	Increase of biodiversity	
		Loss of bird biodiversity	

17. Julia Wiehe

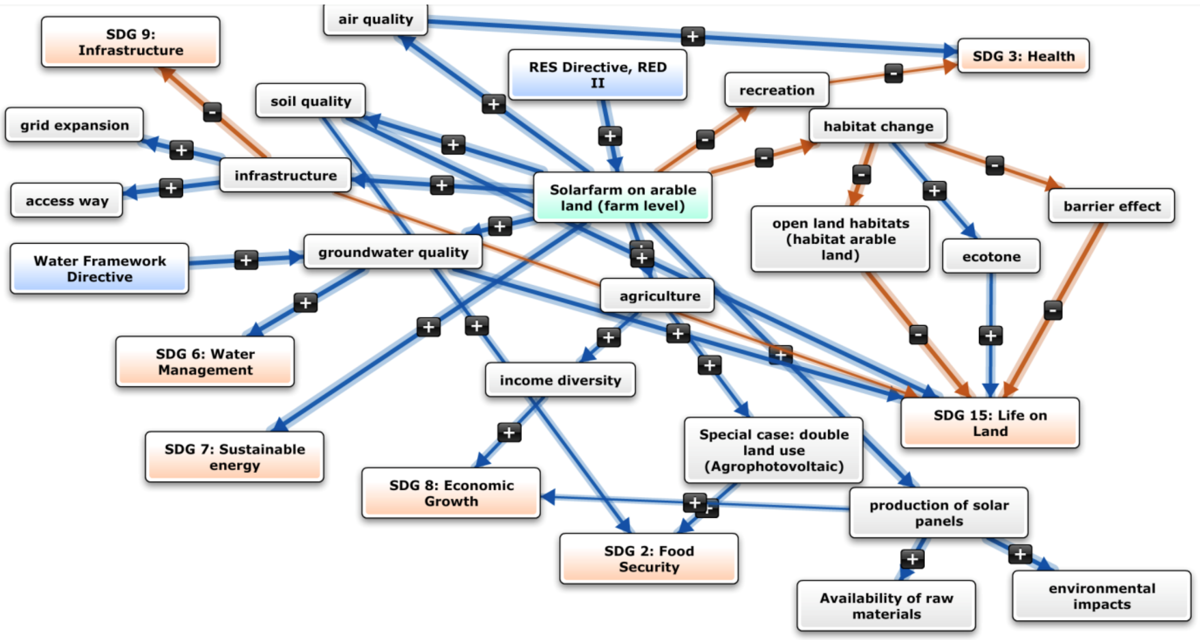

Figure 22: Model produced by Julia Wiehe, focussing on solar farms on arable land.

Policy	Technology	Biodiversity	SDG
RES, RED **Water Framework Directive**	Solar (solar farms, agrophotovoltaic, solar panels)	Habitat change Open land habitats Ecotone Barrier effect Environmental impacts	2 3 6 7 8 9 15

18. Meseret Wondirad

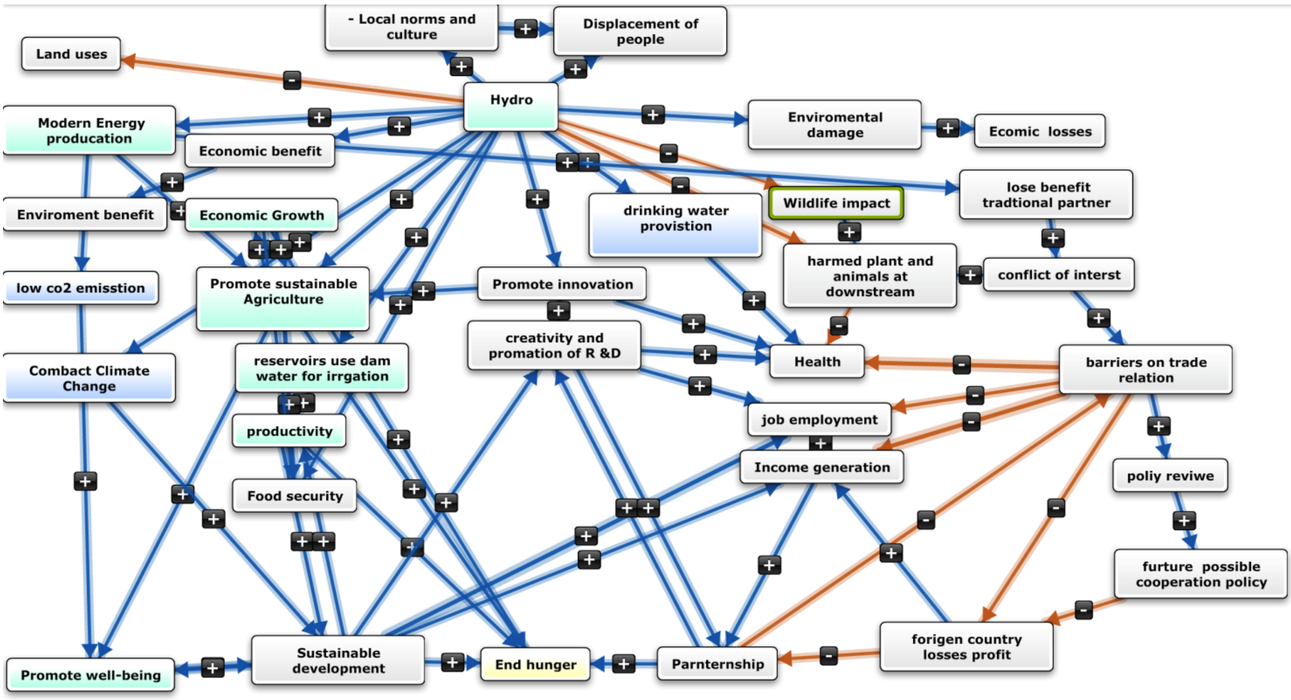

Figure 23: Model produced by Meseret Wondirad, focussing on hydropower and its effects on the environment and the wider societal context.

Policy	Technology	Biodiversity	SDG
	hydropower	Habitat loss Wildlife impact Harm to downstream plants and animals Environment benefit	End hunger Combat climate change

19. Zoltan Rakonczay

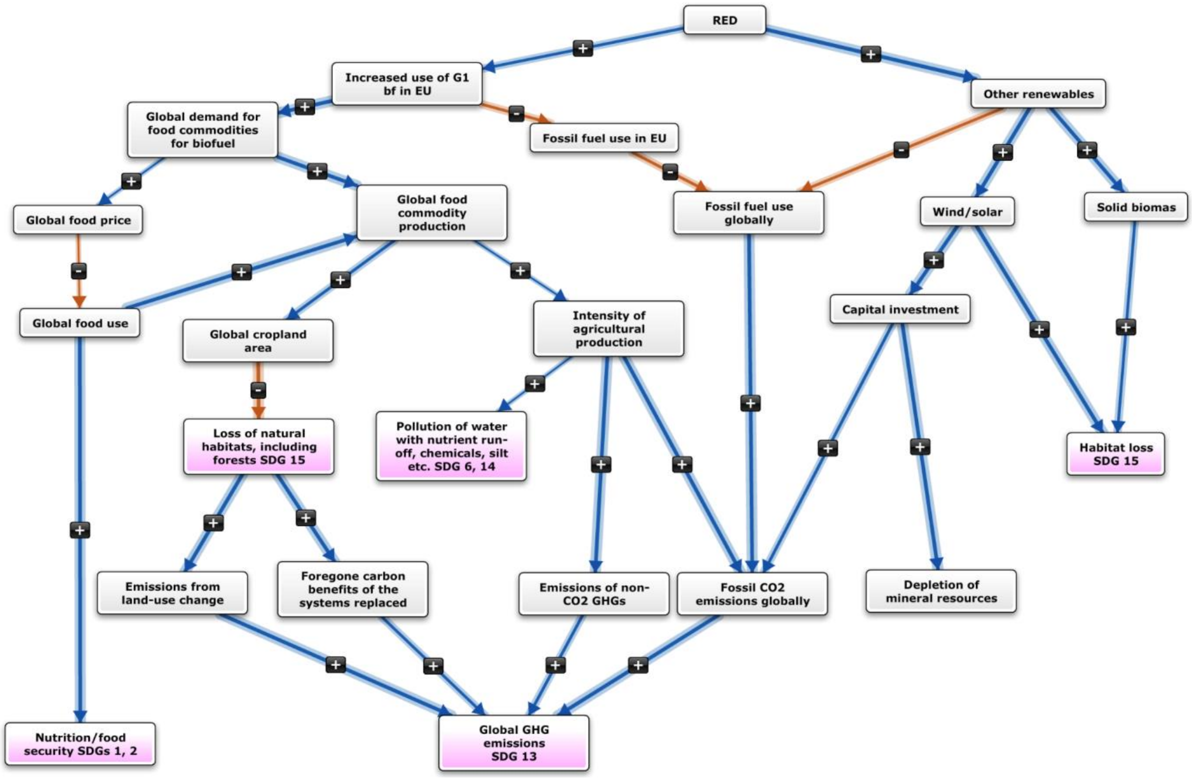

Figure 24: Model produced by Zoltan Rakonczay, focussing on first-generation biofuels, wind and solar, and solid biomass.

This model was only developed on the first day due to participant availability constraints.

Policy	Technology	Biodiversity	SDG
RED	1st generation biofuel	Habitat loss	1
	wind		2
	solar		6
	solid biomass		13
			14
			15

Appendix V: Additional model images

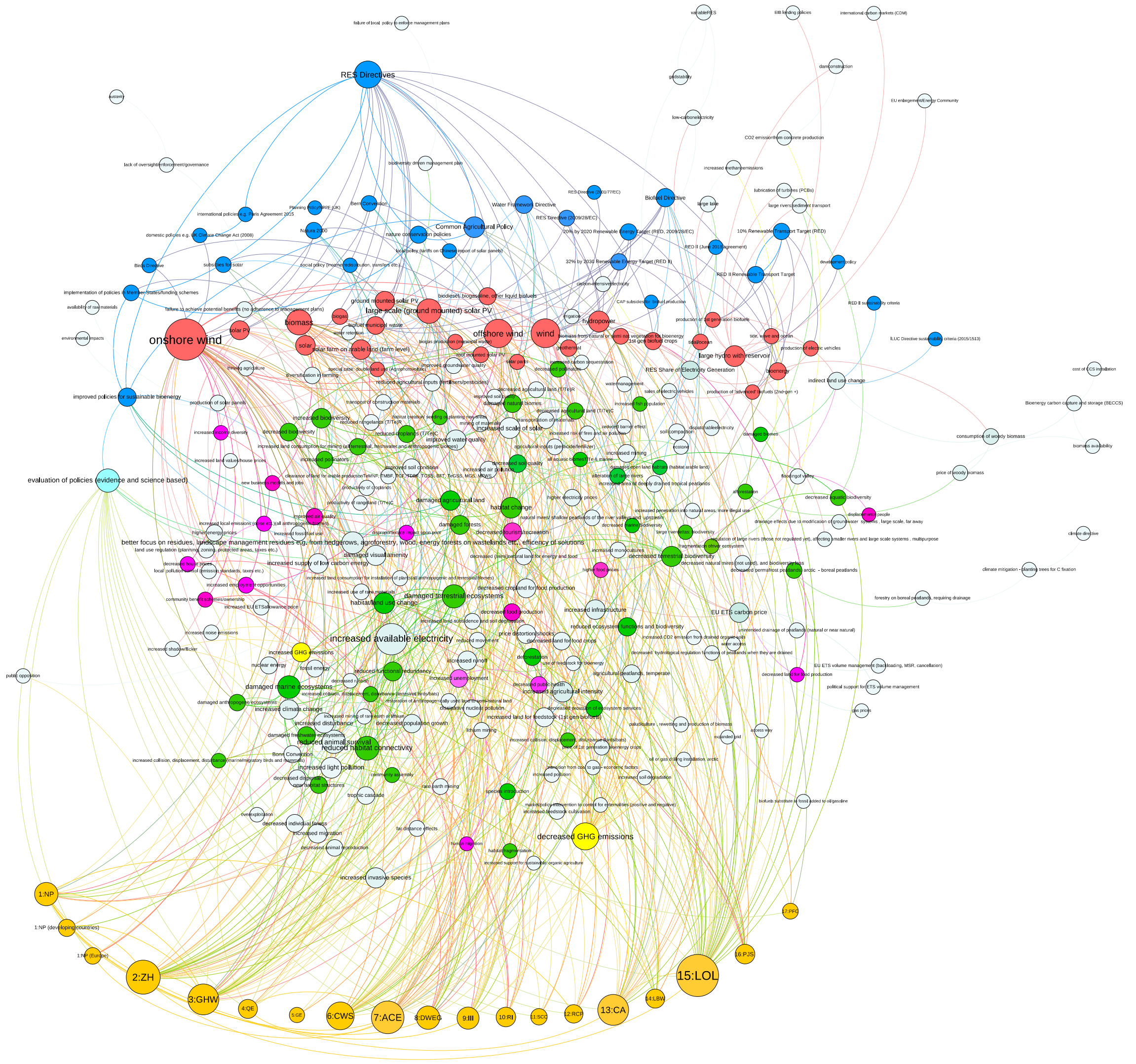

Figure 25: Model with all nodes of degree 2 and above, sized according to degree, and edges coloured according to the interacting source and target nodes.

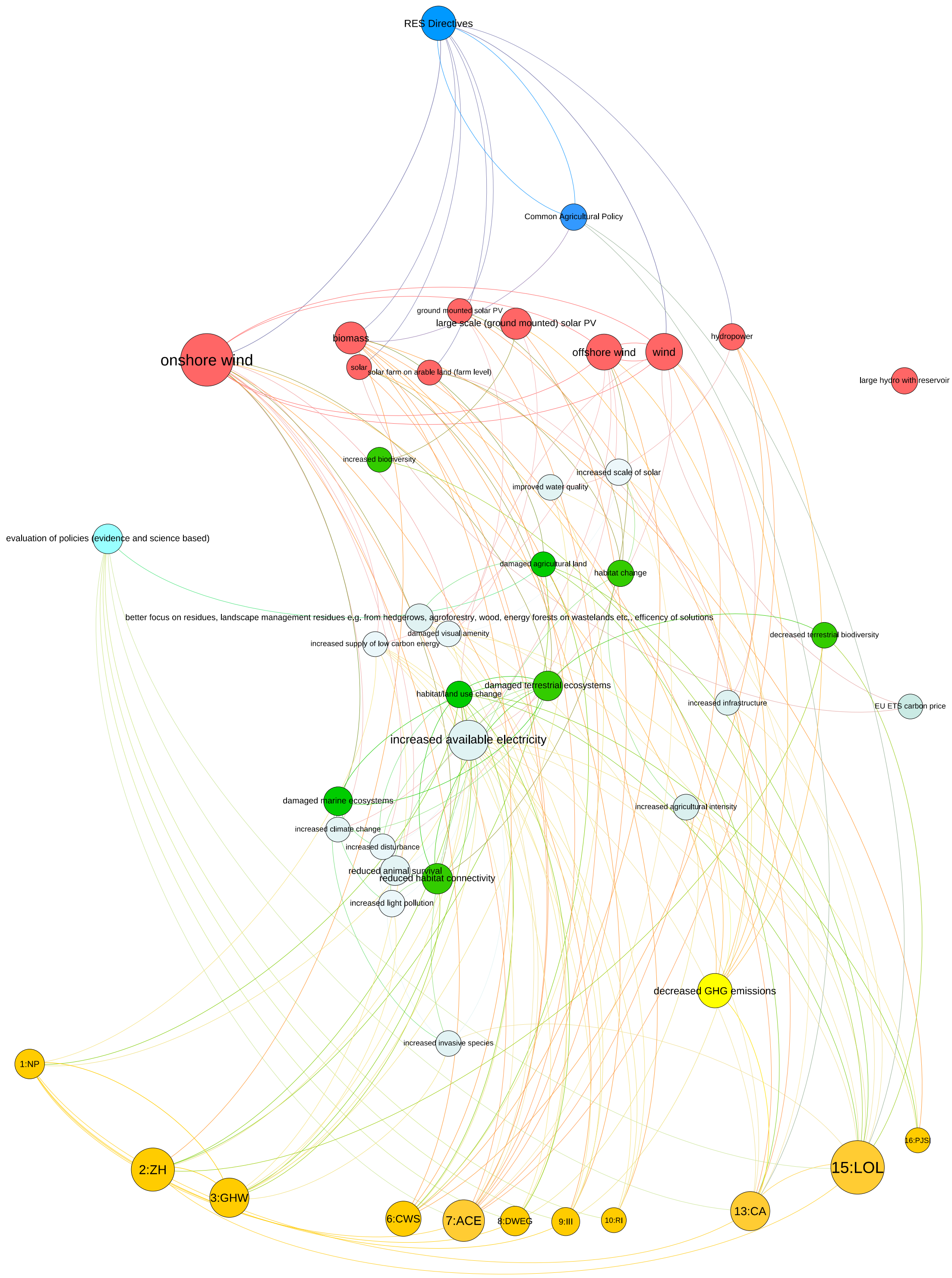

Figure 26: Model with all nodes of degree 10 and above, sized according to degree, and edges coloured according to the interacting source and target node

Appendix VI: Model based on literature review

Here we present the model based on the literature review (Figure 27), and the corresponding values of each link in the model (Table 3). Figure 27 illustrates the negative and positive impacts of different RETs on biodiversity and the associated SDGs, based on the results of the literature review (discussed in Section 3.7). The literature-based model of the system of interacting components was constructed by assessing the linkages between each component. These linkages are coded using a scoring system based on fuzzy cognitive mapping (FCM), in which links are assigned a score. The scores, shown in Table 3, are on the ICSU scale from -3 to 3.

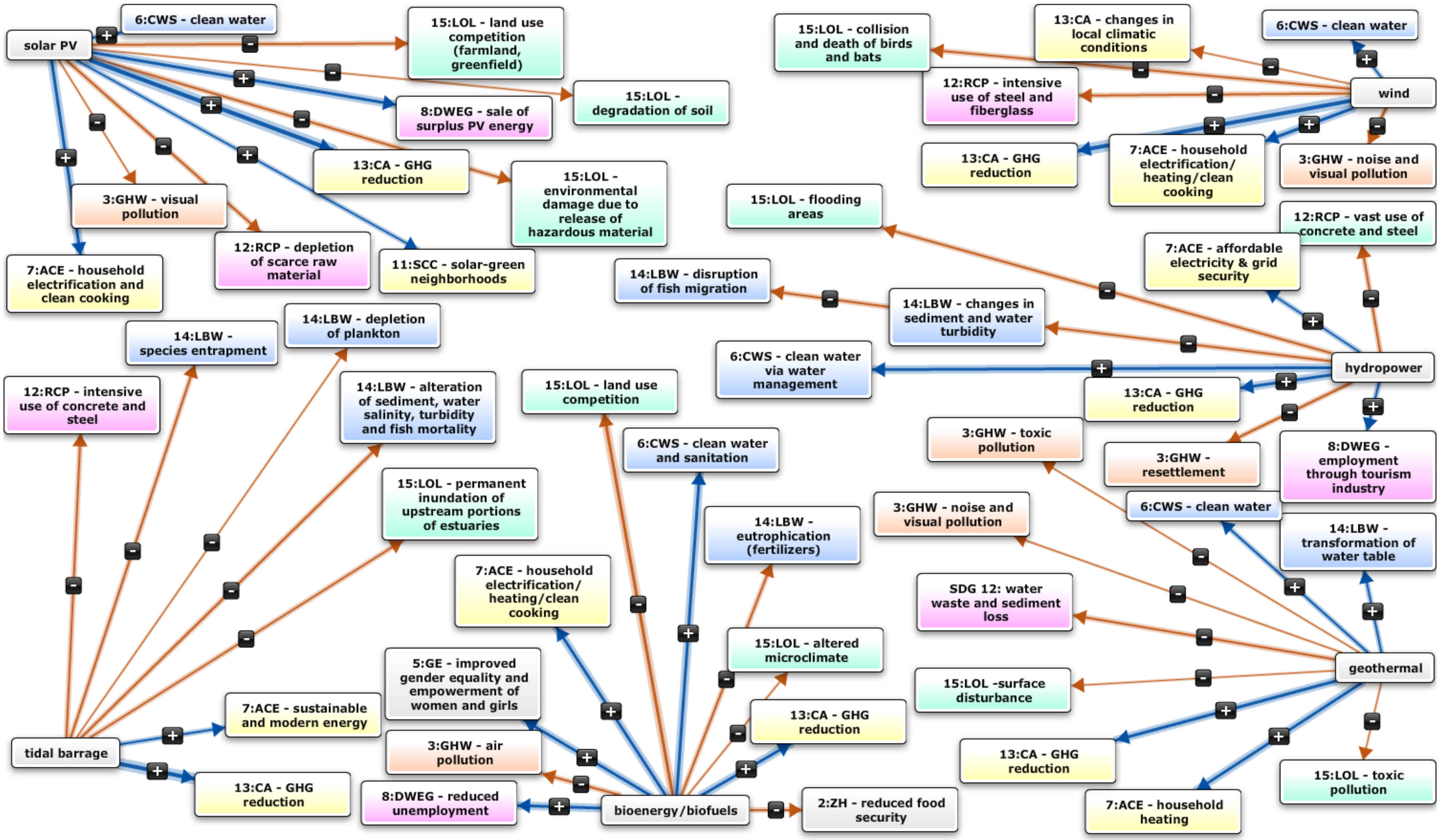

Figure 27: Model based on RET impact scores derived from the literature review, assessing impacts of solar PV, tidal barrage, bioenergy/biofuels, wind, hydropower and geothermal energy (see Table 2). The overall relative impact of an RET on a given SDG is assessed first, then broken down into sub-impacts. These are divided by 3 to comply with the Mental Modeler scale (numbers not shown).

Table 3: SDG impacts of key RETs, based on the literature review, used to generate the model depicted in Figure 25. Scores are allocated according to the ICSU scale, and thus range between -3 and 3.

RET	2:ZH	3:GHW	5:GE	6:CWS	7:ACE	8:GHW	11:SCC	12:SCP	13:CA	14:LBW	15:LOL
tidal barrage	0	0	0	0	0.57	0	0	-0.93	2.67	-1.68	-0.6
solar PV	0	-0.33	0	0.93	2.07	1.5	1.32	-1.2	2.67	0	-1.5
wind	0	-0.93	0	1.17	1.5	0	0	-0.57	2.67	0	-1.26
bioenergy/bio fuels	-0.99	-0.57	1.5	1.5	2.43	1.5	0	0	1.83	-0.93	-0.33
hydropower	0	-1.26	0	1.83	0.93	1.17	0	-0.93	2.16	-1.59	-0.93
geothermal	0	-0.66	0	0.75	1.5	0	0	-0.93	2.43	1.17	-0.66

Appendix VII: The 17 UN Sustainable Development Goals (SDGs)

Figure 28: The 17 UN Sustainable Development Goals (SDGs). Source: UN. (n.d.-g). Sustainable Development Goals. Webpage. http://www.un.org/sustainabledevelopment/sustainable-development-goals [Accessed on 15.08.2018]: United Nations.

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