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Generating socio-economic values from renewable energies

An overview of questions and assessment methods

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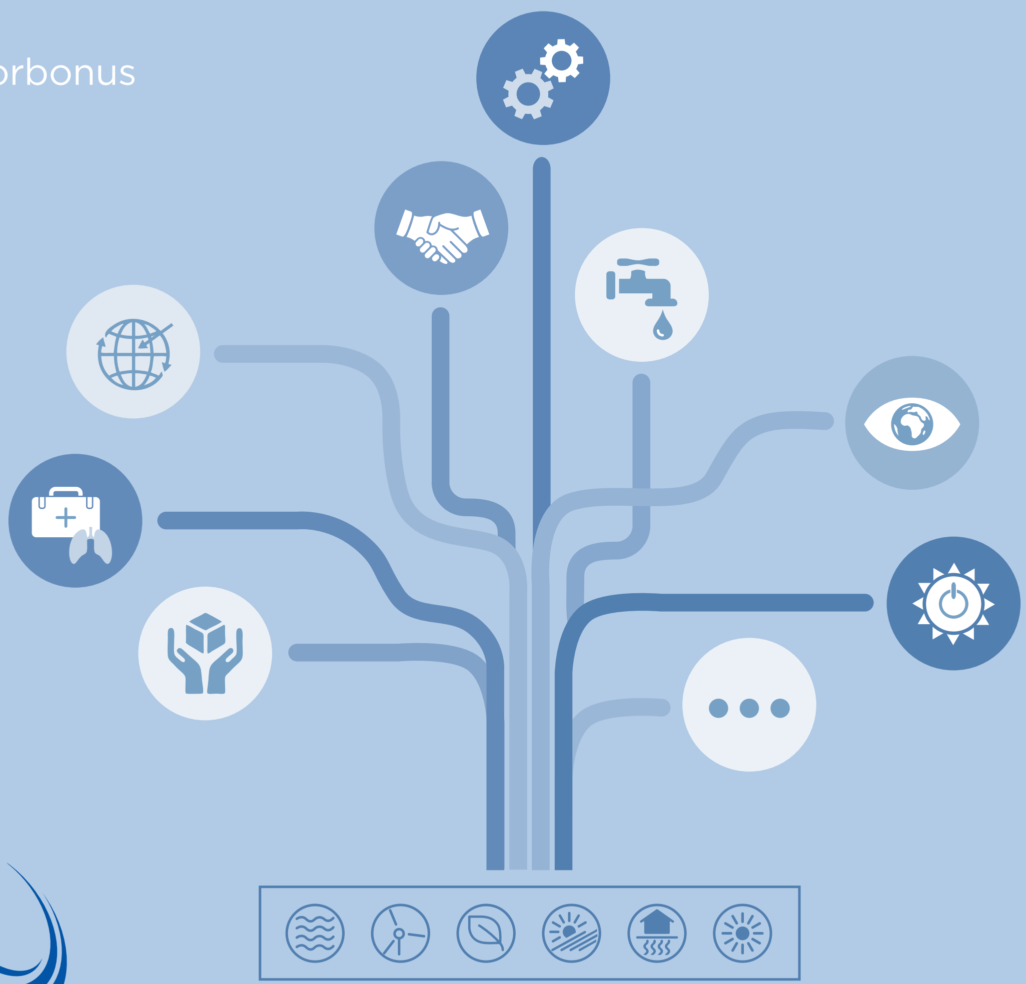

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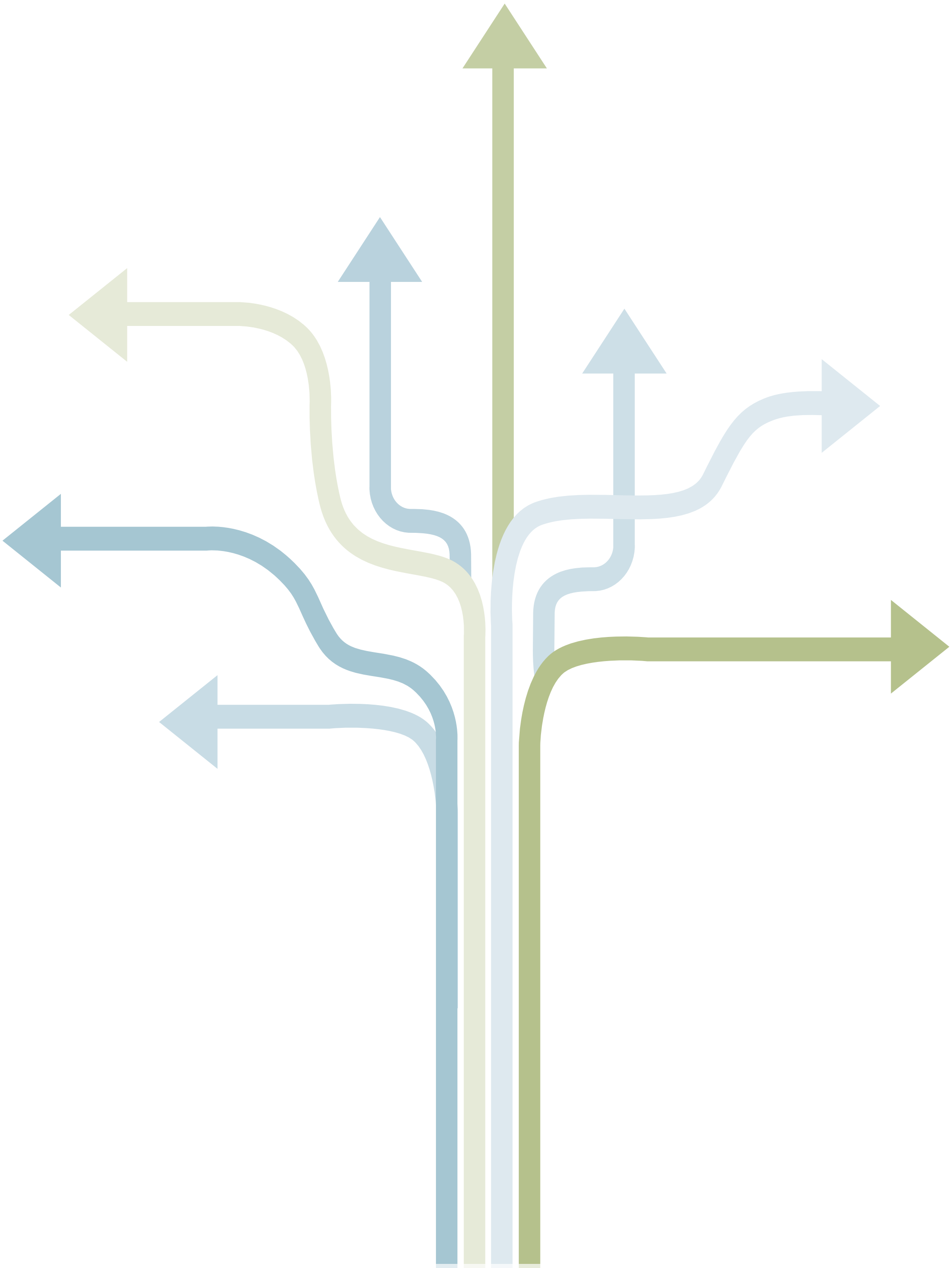

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Abstract

Renewables are seen as to reconcile the urgently needed decarbonisation of energy systems and sustainable economic development. The list of possible social and economic benefits by renewable energies is long. Many of them are already empirically proven, and, throughout the world future prospects of benefits related to renewable energies are a strong argument for NDC implementation and even more ambitious climate mitigation according to the ratchet mechanism of the Paris Agreement.

Still, country-specific co-benefits assessments are often lacking. This is mainly because assessment methodologies are not adapted to specific country conditions and corresponding resource and data availabilities. The author proposes an analytical framework for selecting relevant co-benefits by introducing broad categories that can be refined according to specific country needs. After that an overview on methods for assessing socio-economic effects is given that helps to analyse and quantify selected indicators.

Contents

1. You can't effectively evaluate what you can't measure …

Renewable energies (RE) have received much attention in recent years, not only due to falling technology costs and increasing shares of renewables in energy mixes, but also on account of the multiple benefits that renewables can generate throughout society. The role of renewables as a core strategy in mitigating global climate change is undisputed. What is more, renewable energies are seen as a means to reconcile the urgently needed decarbonisation of energy systems with sustainable economic development.

The multiple benefits of renewable energy go beyond their contribution to climate change mitigation. Many local economies can be strengthened through the potentials of new business fields, job creation and productivity gains, whereas others might suffer economic slowdown due to declining demand for their industrial production. Renewable energies have a favourable effect on health by bringing about improved air quality in cities, for example. Regenerative energy technologies can even make a key contribution to development challenges such as poverty eradication by enabling greater access to energy, especially in developing countries (Rom et al., 2017).

There is already empirical evidence for many of these socio-economic benefits from renewable energies, as demonstrated in particular by the International Renewable Energy Agency (IRENA, 2014; 2016a; 2016b). Yet the advantages of RE do not automatically serve to enable energy policies, let alone ambitious long-term climate action. The root of this problem is that although the terms 'co-benefits' or 'multiple benefits' are often used in discussions on climate change mitigation measures, such terms are rarely measured, quantified or monetised (Ürge-Vorsatz et al., 2014) – except in terms of jobs and gross domestic product (GDP) impacts. For example, with regard to India's commitment to climate protection, in the Intended Nationally Determined Contribution (INDC), renewable energies form "the mainstay of India's climate policy" based on their many development-related co-benefits, including the creation of jobs (Spencer, 2015). In Middle East and North Africa (MENA) countries this assessment is part of a renewable energies roadmap and deployment strategy development (Lehr et al., 2012). In Germany, impact assessments were made to justify renewable energy policy, but in many other countries, jobs are one key element taken into consideration when deciding on renewable energy use or policy.

Generally speaking, assessment methodologies and tools are available (Breitschopf et al., 2011; 2012; IRENA and CEM, 2014). For example, Dubash et al. (2015) established a framework for multi-criteria analysis of climate mitigation benefits that is still in its infancy and has not been tested. More recently, IRENA suggested a comprehensive analytical framework for assessing socio-economic benefits by renewable energies at global scale (IRENA, 2016). However, it is hard to quantify certain benefits due to differing input types and complexity of interactions. Furthermore, analytical frameworks for assessing socio-economic effects often overlook development needs and dimensions that are especially relevant to conditions in developing countries and emerging economies.

One way of dealing with this gap is to propose a set of socio-economic dimensions that also considers conditions and needs in developing countries and emerging economies. Gathering information on the socio-economic impacts of renewable energies is crucial for informed political decision-making and monitoring of energy and climate mitigation policies. To this end, this paper presents a set of criteria, indicators and methodologies for selecting country-specific benefits and gives an overview on assessment methodologies.

2. Rationale and methodological approach

Socio-economic values generated from the deployment of renewable energies can be assessed using various methods, which vary with regard to their applicability and their data requirements. Numerous studies have already been carried out, based on various interests and research questions. But because of differing methodological approaches, system boundaries and assumptions, there can be divergent outcomes even when the underlying questions are similar. This results in a lack of comparability of the studies' results. Many renewable energy impact assessments are resource and data intensive.

However, in many developing countries and emerging economies, detailed data and resources for in-depth studies are not available, and simpler research designs and methodologies are needed. With regard to decision-making tools, Ürge-Vorsatz et al. (2014) come to the conclusion that less complex methods and 'easy-to-use tool kits' should be developed, which can facilitate the assessment of individual co-impacts even by stakeholders at local level, independent of larger targeted research projects. According to the authors, there are not enough practical, targeted and simplified methods and tools that can be used to take impacts into account in climate and energy-related decision-making. For the most part, there are hardly any simple tools available that go beyond economic analysis and analyse socio-economic aspects as well. Such methods and tools should allow broad, practical use and should not require significant resources for implementation. Simple tools for analysing local impacts are very helpful, especially in developing countries. By contrast, country-wide or EU-wide methods require more complex tools that reflect the complexities of the economic relations between countries and regions.

This discussion paper is meant to provide a better understanding of the key parameters and mechanisms that determine or influence how renewable energies impact selected socio-economic effects, while at the same time showing the range of the effects of renewable energies at different levels. Additionally, an overview of relevant scientific approaches for the measurement of the socio-economic effects caused by the transformation of the energy system into a system based on regenerative electricity generation is provided. In other words, in presenting the main socio-economic categories used in scientific literature, we explore the assumptions and methods that form the basis of the respective calculations. For an elaboration of the multiple benefits concept, see Helgenberger & Jänicke (2017).

The objective is to compile a list of potential benefits, their classification and delineation in order to isolate those particular categories, variables and indicators that are most useful and conclusive for analysing the benefits, costs and risks of the expansion of renewable energy in developing and newly industrialising countries. This is meant to help in the selection of suitable methodologies and tools to evaluate the socio-economic impacts brought about by the expansion of renewable energies.

In terms of the methodological approach applied in this discussion paper, the initial step consisted of comprehensive literature and internet research. It focused on studies on the socio-economic effects that come about through the expansion of renewable energies. The keyword search was broadly defined so as to avoid limiting the pre-selection. In addition to peer-reviewed scientific studies, grey literature has also been taken into account. The literature search also encompassed publicly available final reports of research projects commissioned by ministries and federal authorities, publicly available studies as well as publications from international organisations (e.g. IRENA, IPCC). Desk research was restricted to the electricity generation sector, although it does not exclude the heating and transport sectors or energy efficiency measures. In addition to national studies, the paper also takes sub-national analyses as well as the topic of access to energy into consideration.

The discussion paper is organised as follows: In Chapter 3, key terms that are of relevance for the discussion paper are defined. This is followed by an overview of analytical frameworks as well as individual categories and dimensions of socio-economic values (Chapter 4).

Chapter 5 introduces assessment methods. Chapter 6 provides information regarding the selection of assessment methodologies and deals with the integration of socio-economic values in political decision-making tools. The study concludes with a summary of findings and an outlook for further work in Chapter 7.

3. Renewable energies generate socio-economic values

From a sustainable development perspective, the term value creation is broader than its traditional economic definition. It encompasses a vast array of socio-economic effects such as job creation, poverty reduction and reduced negative environmental impacts. This perspective has been taken on by the Global Energy Assessment, which states the following with regard to renewable energies: "Renewable energies offer advantages in terms of supporting all of the goals related to economic growth, energy security, local and regional environmental benefits, health and climate change mitigation. All these advantages imply the creation of value that should be incorporated into the evaluation of different energy options." (GEA, 2012, p. 68).

For the purpose of this study, socio-economic effects are defined as **appraisable and measurable advantages and values of a policy** (**e.g. energy policy**) **to the benefit** of further policy goals. These advantages and values should be considered in the evaluation and the comparison of different energy options (e.g. renewable, fossil fuel and nuclear options). Socio-economic advantages and values created by renewable energies have the following characteristics (based on IRENA and CEM, 2014):

- Level of value creation: Socio-economic effects are generated at different levels, from the global and macroeconomic to the regional or sectoral to the local level. They could have a positive impact in region A and a negative impact in region B. However, even in negatively affected regions, there are non-economic impacts such as less air pollution.

- System boundaries in economic terms: The value chain of renewable energy technologies and their supporting services represent the system boundaries. Socio-economic effects can be measured along the different segments of the value chain, including project planning, manufacturing, installation, grid connection, operation and maintenance and decommissioning. Further opportunities for value creation exist in supporting processes such as policy-making, financial services, education, research and development (R&D) and consulting. The potential for value creation depends to a large extent on the level of development of a country's renewable energy sector.

- Effects: Most effects can be assessed along the value chain and according to their effects on national accounting. The different effects can be differentiated according to their scope into direct, indirect and induced effects. Gross effects can be distinguished from net effects depending on effects only within the renewables sector or effects on the economy as a whole. Health effects, however, are not reflected by national accounting.

- Assessment methods: The different effects can be assessed in a qualitative or quantitative way and even monetised, i.e. expressed in monetary values.

- Beneficiaries: Socio-economic benefits affect different stakeholders than do fossil fuel energy options. The policy goals rural development, poverty alleviation and energy access can mainly be addressed by renewable energies.

Single impulses and effects as basis for a typology of benefits from renewable energies

How are socio-economic impacts generated from economic activities? Each value chain phase of renewable energy technologies consists of economic activities. Each stage (e.g. manufacturing, construction/installation) provides impulses in form of investments as well as operation expenditures related to RE technologies that trigger direct and indirect effects (Breitschopf et al., 2012). Generally speaking, direct effects refer to unintermittently affected industries and consumers. Indirect effects accrue from down- and upstream industries. Besides direct and indirect effects, induced effects arise.

Induced effects comprise substitution effects, price effects, budget effects, income effects, foreign trade effects, dynamic and others effects (Lutz and Breitschopf, 2016). Substitution and saving effects triggered by less deployment of fossil fuels can be direct (dwindling sales of fossil fuels with utilities) and indirect (dwindling sales with power plant manufacturers). Induced saving effects on e.g. households refer to released funds from less fossil fuel demand that result via increased consumption in higher investments in all sectors. Price effects depend on the design of a specific energy policy measure. Price instruments such as taxes and certificates have direct and indirect effects on prices. Impulses from displaced investment and operating expenditures in non-renewables use and exports, including impacts in upstream industries trigger negative direct and indirect effects. Impulses due to energy price changes affect consumption expenditures of the households and the cost structure in the industry (induced effects). Impulses from household incomes due to employment changes in the renewable energy sector and/or in the conventional energy industry trigger induced effects. Foreign trade effects accrued directly from substituting imports of fossil fuels and imports of goods and services related to renewable energy technologies. Positive export effects are triggered by exporting goods and services related to renewable energies. Dynamic effects such as learning effects depicted by global learning curves for renewable energies, that describe the relation between globally installed renewable energy capacities per RE technology and decreasing installation costs.

Exogenously given impulses are the starting point of an economic impact mechanism, which leads to several effects: direct, indirect, and induced ones (see Figure 1). The effects show how impulses affect the economy. They add up to socio-economic impacts, e.g. changes in employment. Some of the effects can be perceived as “negative” by certain stakeholder groups that are affected in a negative way by the energy transition, e.g. by loss of jobs.

For analyzing employment effects of renewable energies in Germany the terms gross and net effects have been established (Staiß et al. 2006; Lehr et al. 2011). These terms are also applied to the analysis of the energy transition as a whole. They even gained acceptance at international level (Lutz and Breitschopf 2016). If gross effects are assessed, a sector-perspective is taken on. Gross effects refer for example to an increase in employment within the RE sector. If net effects are assessed the view is on the economy as a whole. A gross analysis focuses on the contribution of renewables to the economy as a whole. It looks at either the renewable sector on its own or together with the supply industry. The gross analysis conveys an idea of the relevance and structure of the renewables sector, including the role of different technologies and of imports and exports. Net methods are used to examine the influence of the renewables sector on the economy as a whole, including positive (direct, indirect and induced) and negative effects, e.g. due to increased energy prices and job losses in the conventional energy sector. Net analyses look to answer the question of how renewables affect overall employment and welfare. This requires comparing two developments: a business-as-usual scenario and a renewables deployment scenario. Ürge-Vorsatz et al. point out that in developing countries, the scale of an effect does not always have to be determined, but rather that the direction is often sufficient. Because effects often start at a low level, they almost always lead to welfare gains (Ürge-Vorsatz et al., 2014). Table 1 presents the gross and net effects brought about by renewable energies in tabular form.

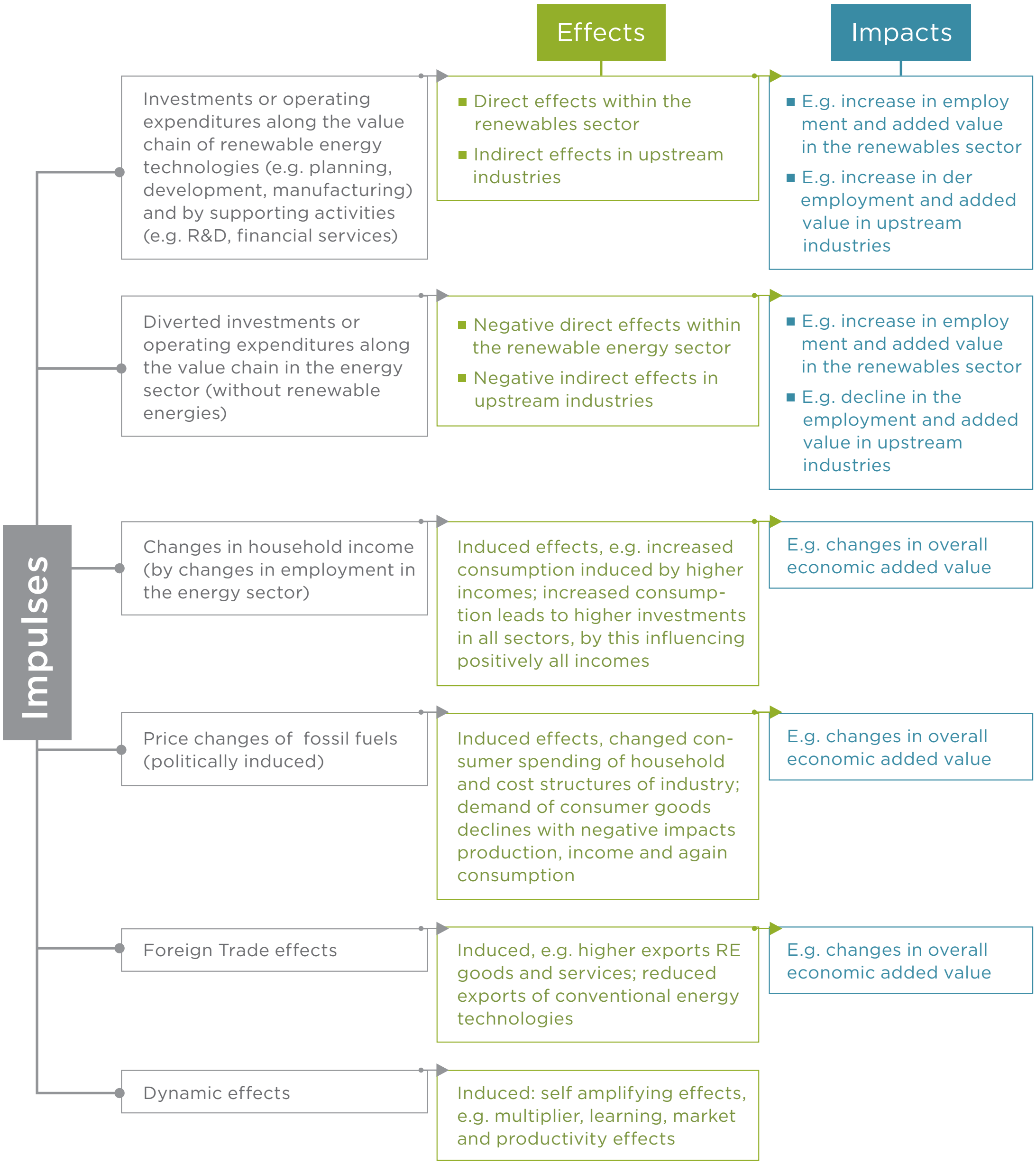

Figure 1: From economic activities to socio-economic impacts: overview on additionally triggered ("positive") and counter/avoided ("negative") effects

Source: Own compilation based on Breitschopf et al. (2012); Lutz and Breitschopf (2016).

Besides positive and negative sector or economy-wide socio-economic impacts such as possible negative net effects in terms of a drop-off in employment in the fossil energy sector, there are also technology- und project-specific challenges relating to the deployment of renewable energies. If challenges are adverse and uncertain, they imply risks (IPCC, 2014). Risks resulting from the expansion of renewable energies should be taken into consideration and minimised in a technology-specific (e.g. increased consumption of critical metals for photovoltaic) and context-specific way (e.g. acceptance concerns related to wind power or displacement due to large hydropower projects).

Gross effects	Net effects
Gross impact refers to the sum of effects in the renwables industry = sectoral perspective	Net impact refers to the sum of effects on the overall economy; effects on the overall economy = economy-wide perspective
Effects: positive, in/direct	Effects: positive and negative, in/direct and induced
Transmits an idea of relevance and technological structure of renewables industry	Looks at all effects at all levels: technological system, micro- and macro-level
Answers the following questions: Which part of overall employment/value creation is linked to the expansion of renewable energies? Relevance of various regenerative technologies? Relevance of indirect employment/value creation in industries that supply REG industry with goods and services?	Answers the following questions: How many jobs are created through the expansion of renewable energies? How many are lost to other sectors? What changes come about in the overall eco-nomy as a result of the expansion of renewable energies?

Table 1: Gross and net socio-economic effects from renewable energies

Source: Own compila-tion based on Breitschopf et al. (2011; 2012)

4. How to analyse country-specific socio-economic effects from renewable energies?

The following chapter attempts to answer the question of which socio-economic effects of renewable energies are relevant from a transnational standpoint, and how can they be integrated into a larger analytical framework to determine socio-economic effects. Based on existing proposals, we develop an analytical framework that can be used to analyse socio-economic effects. The aim of the chapter is not to achieve a complete categorisation, but rather to provide support in the selection of socio-economic effects by suggesting suitable categories.

4.1 Screening of existing approaches for determining socio-economic effects

Four proposals for assessing multiple benefits of climate mitigation are screened in terms of the approach and dimensions of socio-economic effects. The approaches were developed by the Japanese government (2009), the Environment Programme of the United Nations (UNEP) (2011), Dubash et al. (2013) as well as IRENA and CEM (2014) and IRENA (2016).

The Japanese government provided an analytical framework for the assessment of co-benefits in non-monetary form of Clean Development Measures (CDM) projects focusing on indicators related to water quality, air quality and waste management (Ministry of the Environment, Gov. Jp. 2009). Socio-economic effects have not been taken into consideration.

The United Nations Environment Programme (UNEP) developed an analytical framework for co-benefits of climate mitigation and adaptation policies (UNEP 2011). At the heart of this framework is a hierarchical criteria tree containing a set of generic criteria, against which climate policy planners can evaluate proposed climate policy action and their potential contribution to a broad range of climate, environmental and socio-economic development objectives. The generic criteria tree starts with the criteria input and output on the first level. On the second level, seven criteria were developed relating to financing and implementation barriers (inputs), as well as economic, social, environmental, climate impact, political/institutional criteria (outputs). On a third level, the criteria are specified as concrete policy goals such as reduction of inequality or enhanced governance.

The UNEP framework was applied to South African energy policy, comparing six energy scenarios with different technology and fuel mixes (UNEP, 2011). Based on the Integrated Resource Plan (IRP), five second-level criteria were developed: cost, climate mitigation, portfolio risk, regional development and water consumption. The South African case study illustrated the process of iterative improvement of policy planning processes, widening the third level criteria to cover developmental impacts such as poverty and energy access.

All of these approaches are still in their infancy and have yet to be applied and tested. This criticism corresponds to that of Mayrhofer and Gupta (2015), who examined how the co-benefits concept was applied in the Indian energy sector. Among the factors not included in the analysis of various energy policy measures were questions of (re-)distribution, justice and inclusion, as well as hidden trade-offs. Social benefits such as access to energy were neglected, while it also remained unclear how the urban poor can be reached by the co-benefits approach.

Building upon these concerns, Dubash et al. developed a co-benefits-based approach for decision-making in the area of energy policies (Dubash et al., 2013). Based on the 12th five-year plan, the authors propose four outcomes with sub-categories: economic growth (resource efficiency, employment, energy security), inclusion (poverty, inequality), local environment (land, water, air quality), GHG mitigation. Based on this approach, policies are identified, e.g. fostering renewable energies. Even if the co-benefits framework has been adjusted and was included in the 12th five-year plan, co-benefits are still treated in an ad-hoc manner in existing policy initiatives and are not considered to be political decision-making criteria (Mayrhofer and Gupta, 2015).

A comprehensive analytical framework for the assessment of the socio-economic effects of renewable energies was presented by IRENA (2014) on the basis of Fraunhofer ISI et al. (2012). The framework has been applied at global level to the first column on macroeconomic effects of renewable energies (IRENA, 2016). Specifically, the focus is on four variables: gross domestic product (GDP), welfare, employment and trade balance. Three scenarios of the doubling of the share of renewables in the global energy mix by the year 2030 are considered in IRENA (2016): a reference scenario (with information from REmap and additions based on the New Policies Scenario contained in the IEA's World Energy Outlook), the REmap Scenario (based on REmap and additions from the IEA's 450-ppm Scenario) and the REmap Electrification Case (RemapE), in which the electrification of the heating and transport sector is given more weight. The study presents net results, thereby taking both positive and negative effects into account. The study also takes unemployment into account. The analytical framework also incorporates further co-impacts, which are to be quantified in future studies. Among these co-impacts are distributional effects, energy system-based effects, as well as additional effects including, for example, risk reduction (see Figure 2).

The analytical framework was explicitly developed to be applied to renewable energy deployment in developing and newly industrialised countries. Despite the very comprehensive nature of the analytical framework, it must be noted that essential dimensions of socio-economic benefits are missing, which are of significance in particular in developing and newly industrialised countries. Poverty reduction and access to energy, for example, are not included. Rural development or climate mitigation at municipal level, on the other hand, represent important co-benefits of the expansion of renewable energies, not only for numerous developing countries, but for industrialised countries as well. Also not included are impacts on health, for example.

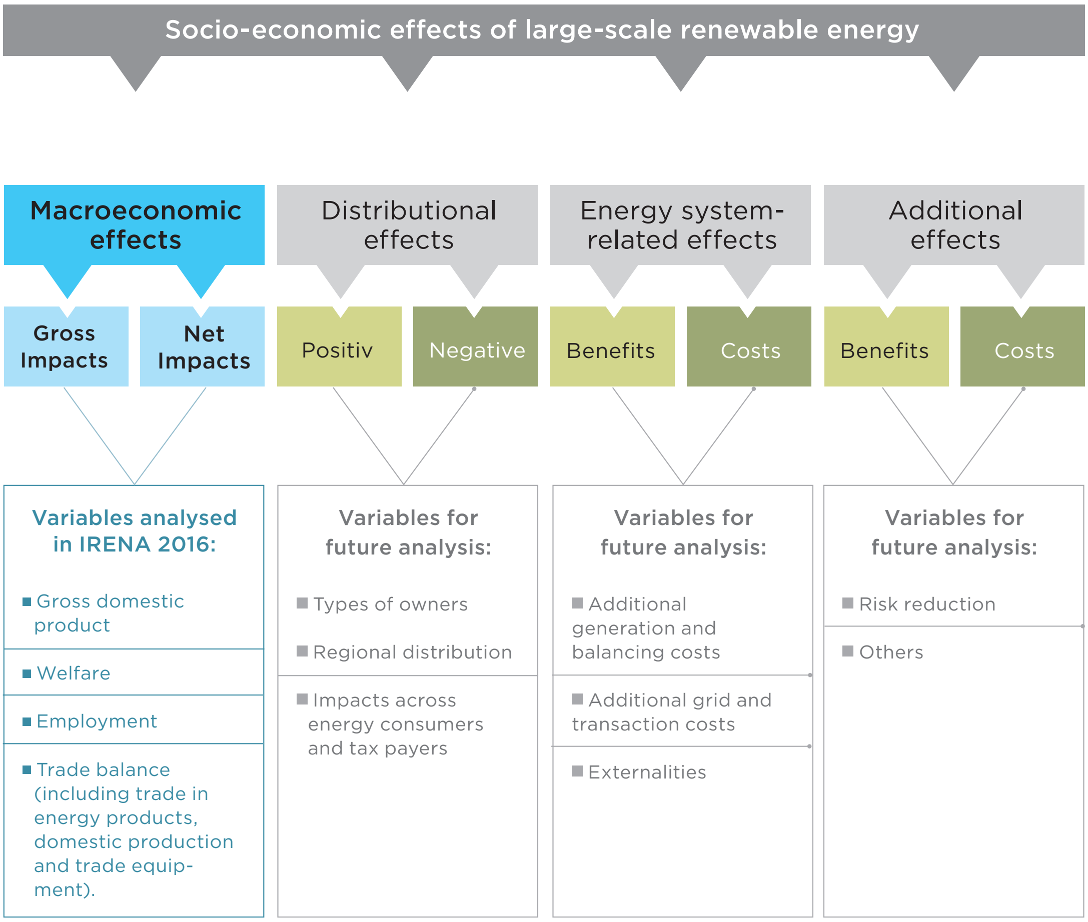

Figure 2: Analytical framework for the assessment of socio-economic effects of the expansion of renewable energies

Source: IRENA (2016), p. 10

4.2 Analytical framework for determining socio-economic effects of renewable energies

Socio-economic effects can represent national policy goals, laid out for example in high-level political documents. National policy goals comprise energy policy goals as well as goals of other policy fields such as public health or industry development. Furthermore, categories can be drawn from international agreements. The Paris Agreement encourages developing and emerging economies to take ambitious climate action. Likewise, the United Nations Sustainable Development Goals are specific policy goals that the international community of states is intent of achieving by 2030. Additionally, categories can represent socio-economic safeguards of an energy system at global and national level. Safeguards encompass e.g. energy security, respect for human rights along the whole lifecycle of energy production and consumption, as well as avoidance of technological risks.

The following section proposes an analytical framework that is intended to help in the identification of socio-economic co-benefits that come about with the introduction and expansion of renewable energies. To this end, a broad categorisation will be carried out – which is, however, not final. The categorisation allows the incorporation of specific sub-categories and energy-related sustainability indicators for certain policies. Interdependencies between the individual effects cannot be taken into account here, although attention is drawn to the risks that can be associated with the expansion of renewable energies. A technology-specific risk analysis is not undertaken.

Direct effects – gross effects – simple indicators

(a) Environment

Renewable energies have the potential to reduce local environmental damage, such as that caused by coal reduction of local air pollution such as nitrogen oxides and sulphur oxide (Sathaye et al., 2011). However, this only applies if these policy objectives have not already been tackled with other instruments. In China, for example, technologies are required to meet flue gas desulphurisation requirements and must eliminate nitrogen oxides and particulate matter (You and Xu, 2010). Murata et al. (2016) looked into the environmental co-benefits of the promotion of renewable power generation in China and India through clean development mechanisms. Ma et al. (2013) calculated the mitigation effect of wind power on CO_2 and air pollutants (SO_2, NOx and $PM_{2.5}$) emissions in the Xinjiang Uygur Autonomous Region in China.

(b) Access to energy

Access to basic energy services is a prerequisite for eradicating poverty and stimulating economic activity. Over one billion people (17% of the world's population), mostly in rural areas of Africa and developing Asia, still do not have access to electricity, while another one billion have only an unreliable supply (IEA, 2011). About 2.9 billion people rely on traditional biomass use for heating and cooking (SE4ALL, 2015), which is an impediment to making advances in the areas of health, gender, equality and economic opportunities in developing countries.

Measuring access to energy is complicated by the subjectivity in its definition (Pachauri et al., 2012). It is widely accepted that access ought to include the affordable and reliable supply of energy services. For instance, countries often present rural electrification rates in terms of the number of villages with access to electricity, but their implicit definitions of an "electrified village" differ (Pachauri and Jiang, 2008). The choice of access indicators includes a normative component. What properties should define access, and how much of the chosen properties should be considered as an adequate level of access? For example, should households have a minimum level of electricity demand met and within a certain budget? Should households have a minimum level of reliability in terms of hours of interruption? Furthermore, since the alleviation of poverty requires the provision of energy to generate livelihoods and provide for common facilities, an assessment of the adequacy of energy services for an economy would require a broader average quantitative measure beyond that for household consumptive uses. In this context, researchers have explored the notion of thresholds for basic energy needs (Imboden and Voegelin, 2000). Pachauri and Spreng (2011) emphasise the necessity to design indicators that adequately assess the needs of beneficiaries and describe the living conditions of families and communities, who are targeted by energy access policies and programmes.

(c) Macroeconomic effects

In every country throughout the world, the energy transition requires investments of many millions of dollars in electricity generation capacities and in energy infrastructure. Figures of investments in renewable energies, in grid extension or generation capacities are generally available. Investments are also an auxiliary indicator for indirect job effects. The energy transition is expected to trigger employment effects through the increased number of small decentralised energy plants, the increased provision of balancing energy and through energy trading. Direct employment effects can by assessed via company surveys and value chain analyses (O'Sullivan et al. 2015). According to Staiß et al. (2006, p.3) direct employment is triggered by the production of renewable energy plants with manufacturers, operators and service enterprises. Generally speaking, direct effects refer to unintermediately affected industries or consumers.

d) Energy security

Energy security, although it lacks a unanimously accepted definition, is generally defined as the uninterrupted supply of energy services, and refers to the robustness, independence and resilience of energy systems (Johansson et al., 2012). For energy importing countries, the reduction of imports through the use of renewables is of key significance. The robustness of an energy system is characterised primarily by the age of the power plant fleet, the frequency of blackouts and the growth in energy demand (Johansson et al., 2012). Sovacool and Mukherjee proposed the dimensions availability, affordability, technology development, sustainability and regulation, and provided a list of 372 indicators (Sovacool and Mukherjee, 2011). Alternative approaches also address perspectives on energy security of non-state actors ranging from global production networks (Bridge, 2008) to households and private consumers (Cherp and Jewell, 2014).

Another aspect of energy security, self-consumption benefits, has not yet been systematically quantified. Businesses and households can increasingly produce and consume some or all of their own electricity. The emerging self-consumption model opens new cost-containment opportunities for energy consumers, particularly for small and medium-sized enterprises (SMEs). Amongst residential consumers, new behavioural patterns are emerging, ranging from rooftop solar photovoltaic (PV) systems owned by individual households or third parties to self-consumption projects developed by citizen-led renewable energy cooperatives. In the context of a smart grid environment, self-consumption has the potential to drive consumers' uptake of flexibility measures (de-mand-side response, energy storage), while at the same time helping to facilitate the system integration of variable renewable energy (Widén and Munkhammer, 2013).

(**c**) **Distributional effects**

Distributional effects represent a further level of socio-economic impact analysis of regenerative electricity production and consumption. Of particular relevance seems to be the distribution between various types of system operators, between different regions and between energy consumers and taxpayers. Additional sub-categories could be vulnerable groups such as women and the poor. Social impacts brought about by renewable energies comprise e.g. distributional effects of a renewable energy surcharge (Diekmann et al., 2016; Lutz and Breitschopf, 2016). The social acceptance of an energy transition depends inter alia on how high the entire financial burden is, as well as on how fairly it is shared between households and enterprises. In the case of Germany, the differential costs of the Renewable Energies Act will be allocated primarily to the non-privileged final consumption of electricity.

Indirect effects – gross effects

(**a**) **Health effects**

Generating electricity from renewable energy rather than fossil fuels offers significant public health benefits. The air and water pollution emitted by coal and natural gas plants is linked to breathing problems, neurological damage, heart attacks and cancer. Replacing fossil fuels with renewable energy has been found to reduce premature mortality and lost workdays, and it reduces overall healthcare costs in the USA (Machol and Rizk, 2013). The aggregate national economic impact associated with these health impacts of fossil fuels is between $361.7 and $886.5 billion, or between 2.5 percent and 6 percent of the GDP.

Wiser et al. (2016) monetise the environmental health benefits of solar, which could add ~3.5¢/kWh to the value of solar energy. Compared with fossil fuel generators, PV and CSP produce far lower lifecycle levels of greenhouse gas (GHG) emissions and harmful pollutants, including fine particulate matter ($PM_{2.5}$), sulphur dioxide (SO_2), and nitrogen oxides (NO_x). Achieving the SunShot-level solar deployment targets – 14% of U.S. electricity demand met by solar in 2030 and 27% in 2050 – could reduce cumulative power-sector GHG emissions by 10% between 2015 and 2050, resulting in savings of $238–$252 billion. This is equivalent to 2.0–2.2 cents per kilowatt-hour of solar installed (¢/kWh-solar). Similarly, realising these levels of solar deployment could reduce cumulative power-sector emissions of $PM_{2.5}$ by 8%, SO_2 by 9%, and NO_x by 11% between 2015 and 2050. This could produce $167 billion in savings as a result of lower future health and environmental damages, or 1.4¢/kWh-solar – while also preventing between 25,000 and 59,000 premature deaths. The reduction of energy poverty in cold regions also has a positive effect on health problems caused by unheated rooms (Ormandy and Ezratty, 2012).

(**b**) **Access to energy**

Decentralised renewables can enable significant savings on fuel spending. In many parts of the world, off-grid solutions are the most cost-effective form of electricity supply. Photovoltaic systems under 5 kW represent an economic alternative to grid expansion when they are located at distances starting at 1 to 2 kilometres from the existing grid, for example (IEA PVPS, 2016). The combination of PV systems and diesel generators in micro-grids mitigates fuel price increases, enables operating cost reductions and is a cost-effective power source for telecom base stations.

With regard to the topic of access to energy and value creation, it is often pointed out that productive uses need to be incorporated in the analysis, and that an assessment using standard economic indicators is not sufficient, as these do not reflect the costs of poverty. It has been shown that improvement of the lighting situation through regenerative energy, for example, can expand educational opportunities and improve school attendance rates. For the assessment of the socio-economic impacts of decentralised energy applications, IRENA suggests an analytical framework targeted specifically at renewable energy in the area of food processing (IRENA, 2016). Accordingly, it is necessary, although beyond the scope of this study, to introduce alternative ways of measuring welfare, for example measurements that correspond to the concept of development as an increase of freedom of choice (Sen 1999).

(**c**) **Energy security**

Even if the meaning and concept of energy security have varied over time, some issues have remained firmly on the agenda. A reduction of global interdependence can be measured by the trade balance (IRENA, 2016). IRENA draws attention to the advantage of the expansion of renewable energies for energy exporting countries: If the use of renewables leads to a lower consumption of fossil fuels within a country's borders, more fossil fuels can be exported. The use of renewables enables makes it possible, for example, for African interconnection grids to export power to neighbouring countries. Many developing countries suffer from the price volatility of fossil fuels, in particular oil (Edenhofer et al., 2013). Declines in energy prices – both the commodity prices on the global market (oil, coal, gas) and retail prices – have a significant influence on the energy transition. The causes of the changes in energy prices cannot be influenced by direct intervention (Kirchner et al., 2016). An indicator for the increasing diversity of resources and technologies, and thus also for the resiliency of the energy supply system, is therefore needed. However, renewable energies often play an insignificant role in reducing oil imports, which are essential in particular for the transport sector. It is more common for renewables to replace coal and gas. When significant domestic fossil fuel resources exist, the contribution of renewables can remain small unless a long-term diversification of primary energy sources takes place.

(**d**) **Macro-economic effects**

Besides direct job effects through an increasing number of decentralised power plants and increased energy trade, further jobs are generated in downstream and upstream sectors such as plant construction and engineering, construction industry, skilled craft and trade, maintenance and financial services. Indirect job effects through investments are assessed with the aid of macroeconomic models (see Chapter 5). Direct and indirect employment amount to gross employment (Staiß et al., 2006; O'Sullivan et al., 2014). These terms also apply to the assessment of the economic relevance of other sectors, e.g. the regional economic relevance of lignite coal (Prognos, 2011).

e) **Distributional effects**

Ownership structures are crucial for the share of local value creation. For developing and newly industrialised countries, a distinction can be made between 'utility scale' and 'distributed' energy plants, as they usually belong to utility companies and to private households, respectively (IRENA, 2014). The regional distribution of renewable energy installations, for example across states, provinces, regions and municipalities, serves several purposes: It illustrates structural change, facilitates political measures at sub-national level and builds acceptance and public support.

The design of policies and instruments is crucial for the question of which actors are financially engaged in the deployment of renewable energies. A sufficient number of actors (low market concentration is a prerequisite for competition, free price building and consecutively low prices e.g. in electricity generation auctions. Bayer et al. developed the indicators "cumulative number of owners", "cumulative market share of the five biggest owners" and "relationship between supply and demand" and analysed the ownership structure in four countries (Bayer et al., 2016).

Slee (2015) considers the potential rural development benefits of community ownership or co-ownership (or equity participation) of on-shore wind energy developments in Scotland. Previous authors have argued that if communities are given a stake in renewables enterprises this will support the Scottish Government's community empowerment agenda, increase economic activity in rural Scotland and provide substantial benefits to rural communities. Others have argued that community ownership schemes may decrease community resistance to on-shore wind developments, and set beneficiary communities on a low-carbon development pathway through stimulating 'energy citizenship'. However, empirical evidence to support these claims remains limited.

(**f**) **Energy system related effects**

Energy system related effects include the electricity generation or differential costs of renewable electricity generation, the grid expansion costs as well as the costs of achieving a more flexible power plant fleet. If the heating sector is included, the costs of energy-efficient building refurbishment are an additional sub-category. Avoided environmental damage is also part of the scope of analysis. Additional costs of generation can be calculated using the electricity generation costs (levelised cost of electricity/LCOE) – a simple approach for comparing the costs of various electricity generation options, which in contrast to the differential cost approach does not take into account the merit order effect. In some countries, the cost of producing electricity from renewable energies has dropped to levels that are close to or even below the retail price of electricity (grid parity), or in some cases levels that are even close to or below the wholesale price of electricity. In several countries, "fuel parity" has already been reached. This means that producing electricity with a PV system, for example, is now in most cases cheaper than producing it with a diesel generator (IEA PVPS, 2016). Costs associated with the balancing of intermittent energy can include the costs of offsetting forecasting errors. In addition, there are the costs of activating or deactivating power plants.

Induced effects

(a) Environment

IRENA (2016b) quantifies climate change externalities related to the combustion of fossil fuels and bioenergy around the world. The assessment is part of a broader analysis to lay out a roadmap to double the share of renewables in the global energy mix by 2030. Annual savings related to climate change could amount to between USD 200 billion and USD 1 trillion depending on how carbon emissions are priced.

At present, energy production accounts for nearly 15% of global freshwater withdrawals – or 580 billion cubic metres (m^3) of water – every year (IEA, 2012). This includes water use during primary energy production and electricity generation. Of this water withdrawal, nearly 66 billion m^3, or 11%, is not returned to the source and therefore is deemed to be consumed (Lavelle and Grose, 2013). Where water resources are limited, technologies that impose less strain on water resources may be preferable. Renewable energy technologies such as solar photovoltaics (PV) and wind consume little to no water during operations, compared to fossil fuel-based plants that require large amounts of water during the different stages of energy production (IRENA, 2015). Water is a critical input for fuel extraction and processing as well as for power generation. The risks that the water sector presents to energy security have been studied widely (UN Water, 2014; World Bank, 2013; Hoff, 2011) and can be summarised as follows: shifts in water availability and quality, resulting in reduced reliability of supply and increased energy demand for water production, treatment and distribution, with potentially destabilising impacts on the energy system.

(b) Macro-economic effects

In many countries, especially in newly industrialised countries, industrial value creation is a driver for the expansion of renewable energy sources. Value creation as measured by the gross domestic product does have its justification; the rate of change in the real GDP is the standard unit of measurement for economic growth. The 'green growth' argument is used in this context: Renewable energy sources contribute to the growth of the gross domestic product, while at the same time reducing greenhouse gas emissions (UNEP, 2011). It is possible to estimate the business value of renewable energy technologies. The value corresponds to the internal market of a country, without taking imports and exports into account. The business value can be estimated based on the average system price (IEA PVPS, 2016).

The welfare index is considered to be an alternative to the GDP; it is a way of measuring the welfare of a society and takes into account additional dimensions in which renewables can make a positive contribution. A composed indicator proposed by IRENA comprises the dimensions health and employment, as well as climate change and material consumption (IRENA, 2016). The trade in goods and services in the area of renewable energy is growing steadily (UNEP, 2013); this includes goods and services for establishing production sites abroad. Due to its considerable economic and social significance, employment is another important effect. In contrast to gross employment effects, a net employment analysis is used to examine positive job effects induced by renewable energies deployment as well as job losses in other sectors. Macro-economic effects can also be seen in international trade, both with fossil fuels and with goods and services. More attention is now being devoted to end-of-life management of renewable energy technologies. IRENA, for example, estimates the potential material value achievable through recycling PV systems to the year 2030 at USD 450 million (IRENA, 2016d).

(c) Distributional effects

The economic development of rural regions is an important topic both in industrialised and in developing countries. Plankl (2013) demonstrates how in Germany value creation and employment are higher in rural regions than they are in urban regions. Hirschl et al. (2010) examine the dimensions corporate profits, net income and taxes for municipalities in Germany. Nesbit et al. (2016) use case studies from six countries to analyse the effects of the expansion of renewable energies on the local economy. One of the research questions they ask is how economic impulses can be maintained beyond the construction phase of regenerative electricity plants. Effects of burdens by income group induced by the German energy transition have been analysed by Lutz and Breitschopf (2016) and Sievers and Pfaff (2016).

(d) Social and other effects

Guruswamy (2010) was one of the first to define energy justice, framing the term as a moral obligation to ensure that those without access to clean energy have access to energy technologies. In the meantime, energy justice has evolved to incorporate principles of climate justice, environmental justice and energy democracy (Sovacool and Dworkin, 2014). Baker (2016) defines energy democracy in a way that it provides affected communities a role in determining the types of energy distributed to them – clean or fossil fuel based – as well as the types of entities that distribute it. Communities should also have participatory rights vis-à-vis financing mechanisms or other contractual mechanisms that incorporate mutually beneficial terms. Accident risks and waste streams of different power generation technologies as well as the public perception of these technologies have been compared by McCombie and Jefferson (2016). Table 2 shows the above-mentioned socio-economic co-impacts and possible sub-categories.

Table 2: Typology of socio-economic benefits

Source: Own compilation based on Johansson et al. (2012), IPCC (2014), Ürge-Vorsatz et al. (2016), IPCC (2014), IRENA & CEM (2014), IRENA (2016), Edenhofer et al. (2013), von Stechow et al. (2015).

Category of effect	Sub-category	Indicator		Examples and literature
		Physical Indicator	Monetary indicator	
Direct effects/gross effects (simple indicators)				
Environment	Reduction of local emissions (particulate matter/ PM; nitrous oxide/ NO_x; sulphur dioxide; non-methane volatile organic compounds	e.g. SO_2 g/kWh	n.a.	You and Xu (2010); Sathaye et al. (2011); Ma et al. (2013); Murata et al. (2016)
Access to energy	Access to modern energy services (power)	Additional consumed KWh of on-grid/off-grid electricity; Number of households with modern energy services (e.g. connected to grid	Willingness to pay for an additional unit of energy (e.g. price per kWh) or for access to on-grid/off-grid electricity (cost per household)	Sagar (2005); Birol (2007); Pachauri and Spreng (2011); unclear net effect: off-grid RE access versus higher energy prices; storage battery collecting systems;
	Affordability of energy services (power)	Share of energy expenses in total household budget; share of energy expenses and annualised cost of end-use equipment in total household budget	Per unit cost of energy (e.g. cost per kWh)	
Macroeconomic effects	Investments	Investment in renewable energy technologies	USD/year	O'Sullivan et al. (2015)
	Gross jobs	Jobs in construction and O&M (fulltime equivalent/year)	n.a.	
Energy security	Resilience	Diversity of resources and technologies	n.a.	Kirchner et al. (2016)
	Reduced fossil fuels imports	Tonnes reduced	USD/ton	Öko-Institut (2015)
	Self-consumption benefits	Self-produced and consumed electricity (kWh per year)	Energy cost savings (USD per year)	Widén and Munkhammer (2013)
Distributional effects	Regional distribution	Number of regenerative electricity plants	n.a.	Plankl (2013); Coon et al. (2012)
	Effects for final customers and taxpayers	Retail electricity prices	Cost per unit of energy	Pudlik (2015); methodological approaches Dieckmann et al., (2016); Lutz and Breitschopf (2016)

Table 2 (continued): Typology of socio-economic benefits

Category of effect	Sub-category	Indicator		Examples and literature
		Physical Indicator	Monetary indicator	
Indirect effects/gross effects				
Health effects	Due to lower SO_2 emissions	Avoided cases; avoided hospi-talisation; restricted activity days, years lived with disability; disability-adjusted life years (DALYs); quality adjusted life years, years of life cost	Avoidance cost ap-proach; willingness to pay/WTP	Sathaye et al. (2011); You & Xu (2010); Grieshop et al. (2011); Wiser et al. (2016)
	Energy poverty related			Ormandy and Ezratty (2012)
Access to energy	Productive utilisations	Value creation through productive utilisations (number of units of produced and processed products)	Revenues minus costs per unit of produced and processed prod-ucts	Productive utilisations in food processing (IRENA, 2016)
Energy security	Security of energy supply	Units of avoided energy imports (e.g. oil barrels)	Cost per unit of imported energy (e.g. cost per oil barrel) Willingness to pay for secure energy supply (e.g. cost per MWh)	Breitschopf et al. (2016); Sovacool and Mukherjee (2011); Cherp and Jewell (2014)
	Diversity and resilience	Diversification of energy mix (e.g. number of primary energy sources used)	n.a.	Johannson et al. (2012)
Macro-economic effects	Upstream industry production	Investment in renew-able energy industry	USD/year	IEA-RETD (2014); Duscha et al. (2016)
	Upstream industry jobs	Jobs (full-time equivalent/year)	n.a.	
Distributional effects	Ownership structure or change in opera-tor structures	Number of different owners (e.g. utility-scale vs. distrib-uted) and resulting revenues	USD/year	Slattery et al. (2011)
Energy-related effects	Costs of additional generation and offsetting	Grid parity and fuel parity	LCOE (compared to retail price, wholesale price, fuel price)	IEA PVPS (2016); Breitschopf et al. (2010); Breitschopf et al. (2015); BMWI (2016)
	Additional grid and transaction costs	Costs per km of grid extension; cost of grid extension for lines between 50 and 100 kV	USD/year	Klobasa and Mast (2014) (2016)
Induced effects				
Environment	Climate	GHG emissions per unit of GDP; avoided costs of climate change or environ-mental damage	Tce/USD; CO_2 price/ ton CO_2e	IRENA (2016b)
	Water	Limited or unreliable access to affordable energy necessary to extract water; re-allo-cation of water resources from other end-uses to energy; contami-nation of water resources due to energy extraction and transformation processes	n.a.	IRENA (2015)

Table 2 (continued): Typology of socio-economic benefits

Category of effect	Sub-category	Indicator		Examples and literature
		Physical Indicator	Monetary indicator	
Induced effects				
Macro-economic effects	GDP/growth	Rate of change of real GDP as measurement of economic growth	Increase of GDP in % (e.g. constant US dollars in 2015 omitting purchasing power parity)	GDP is a standard unit used to compare the economic output of different countries; e.g.
	Welfare: IRENA (2016) proposes a combined indicator consisting of one economic, two environmental dimensions with different weightings	Consumption + future consumption as a measurement of welfare; expenditures for health and education supplement employment; annual greenhouse gas emissions in CO_2 equivalents and direct material consumption in tonnes	n.a.	UNEP (2011), IRENA (2015); Duscha et al. (2016)
	Employment	Number of employees	Net income	IRENA (2016)
	Trade with fossil fuels/electricity and with investment goods and services	Trade balance	Net exports of all goods and services, e.g. in constant USD in 2015 and as share of GDP; trade with fossil fuels in constant USD in 2015	IRENA (2014): Employment is an established indicator based on data from official statistics; Lehr et al. (2015); Ragwitz et al. (2009); Duscha et al. (2016) UNEP (2013); IRENA (2016); Höhne et al. (2016)
Distributional effects	Inequality	Effects of burdens by income groups	USD/year	Lutz and Breitschopf (2016); Sievers and Pfaff (2016)
	Regional value creation and employment	Profit after taxes Net annual income Municipal taxes	USD/year	Direct and indirect effects from the operating phase of installations as well as induced effects (Kosfeld et al. 2013; Hirschl et al. (2010); Hauser et al. (2015); IEA (2016)
Social and other effects	Participation and inclusion	Participation of stakeholder groups (especially vulnerable groups) in decision-making processes; number and distribution of distributed electricity generation NGOs; number and distribution of communities participating in renewable energy development	n.a.	Guruswamy (2010); Sovacool and Dworkin (2014); Baker (2016)
	Minimisation of technical, financial, geopolitical of risks	Actual benefits and drawbacks of different power generation technologies, e.g. in terms of accident risk and waste streams	n.a.	McCombie and Jefferson (2016)

The various categories and sub-categories of effects can be used to create analytical frameworks that can be adjusted to different questions and data requirements associated with the expansion of renewable energies. While the socio-economic benefits described above are relevant in many economies, country-specific economic and social conditions will play an important role in their prioritisation. Different countries will assess individual benefits and effects differently. Even within one country, different actors will be interested in different effects. It should also be remembered that the assessment of effects at regional or local level is very context-specific. The risks that the expansion of renewables brings with it must be viewed from a technology-specific perspective. Although centralised PV is evolving quickly, utility-scale PV has been criticised in light of environmental concerns about the use of agricultural land (IEA PVPS, 2016).

In certain cases, looking at net results alone is not enough (Ürge-Vorsatz et al., 2014). A narrower analysis unit (e.g. a specific stakeholder group) should be used complementarily to gain an understanding of co-benefits and costs for individual societal groups, the poor for example. Distributional questions can, however, also be answered from within the analysis.

5. Overview of assessment and measurement methods

There are many models and tools used to assess socio-economic benefits, and they vary considerably by degree of complexity, data requirements and underlying assumptions. Generally speaking, in terms of sectoral scope, a distinction can be made between net methods and gross methods. The gross approaches encompass employment factors, gross input-output analysis and value chain analysis. Gross methods are presented in IRENA and CEM (2014), and, with a particular focus on employment effects, in Breitschopf et al. (2011); (2012). Net methods refer e.g. to net input-output methods, macro-economic models, general equilibrium models and economic simulation models. An overview of net approaches is found in IRENA and CEM (2014); IRENA (2016); Breitschopf et al. (2011); (2013); EPA (2011).

Many socio-economic impacts can be assessed with existing methods, tools and modelling platforms. Some impacts may require using familiar tools in combination, adapting them slightly or learning to integrate proven methodologies from other disciplines (IEA, 2014). A first estimate of impacts can often be carried out using basic calculation methods, such as estimating the direct costs and benefits using simple spreadsheet software. However, a first challenge consists in valuing non-market impacts. A second challenge consists in assessing induced effects as they require feedback mechanisms to allow inclusion of effects induced in other parts of the economy. This chapter gives an overview, first, on how to estimate and model the direct and wider socio-economic impacts, and second on how to attribute value to all observed impacts.

5.1 Gross methods

Employment factors

Studies applying employment factors describe the economic significance or the scope of the renewables industry with regard to employment. They also offer an assessment of the future role of the renewables industry within the context of a continuing support regime (Rutovitz and Atherton, 2009; Wei et al., 2010; Rutovitz and Harris, 2012; NREL, 2013). Additional aspects included are the regional distribution of employment effects as well as qualifications and working conditions. Many studies include an appeal for continued support for the expansion of renewable energies (Breitschopf et al., 2011).

Employment factors are deemed to be the fastest and simplest approach for assessing employment by renewable energies. They indicate the number of jobs (measured in full-time equivalents) generated per unit of installed capacity or energy produced in megawatts (MW) or megawatt hours (MWh)(IRENA, 2013; 2014). Approaches that are based on employment factors assess the employment effects by multiplying the installed capacities of renewable energy installations, capacity expansions (e.g. in MW) or energy generation (in GWh) with employment factors (jobs per MW or GWh). Employment factors are technology-specific and are assessed for each lifecycle phase. Whether manufacturing takes place in industrialised or developing countries affects the employment intensity (indicating what percentage of an increase in employment leads to a one percent increase in economic growth). In developing and newly industrialised countries, the labour productivities (indicating the rate of output per worker per unit of time compared to an established standard or expected rate of output) are considerably lower than in industrialised countries, thus increasing the number of jobs per megawatt. Since manufacturing also takes place abroad, international trade must be considered as well (Breitschopf et al., 2011). Jobs should be differentiated between those that are created one time only, e.g. in the construction phase, and jobs that exist throughout the entire lifetime of a plant.

Employment factors are based on data from current renewable energy installations or feasibility studies, or on data from companies in the renewable energy industry. To obtain employment factors for all parts of the world, including from developing countries, Rutovitz and Atherton use the differences in labour productivity between respective regions (2009). Factors from OECD countries are thereby adapted to other regions (Breitschopf et al., 2012). Data for the assessment of employment factors can be gathered from working time requirements, technology cost analyses, company surveys and expert opinions.

Wei et al. (2010) expand on a prior study by Kammen et al. (2004) in determining employment factors; using a comparison of different employment factors for relevant RE technologies in various studies, they construct an analytical model that allows a projection to the year 2030 under various scenarios. Rutovitz et al. (2010) determine employment factors for South Africa. A compilation of assessments on employment factors for different regenerative power technologies is provided in IRENA (2013). In addition to the study, Teske et al. (2012) conducted a global analysis. A calculation of employment factors for the Middle East is found in Zwaan et al. (2013). Available tools are the Green Job Calculator (Wei et al. 2010) for the analysis of employment effects; see also Rutovitz et al. (2010), IRENA (2013) and Teske et al. (2012).

Employment factors can present an accurate and technology-specific approach if data sources are accurate and reliable (Breitschopf et al., 2011). However, most studies utilise a small number of data sources, and the employment factors vary considerably from source to source (up to a factor of 4). The majority of studies concentrate on direct employment in the renewable energies industry. Induced effects are not considered. The differing system boundaries often prevent a comparison between the studies. The creation of employment factors is often not sufficiently documented, and different countries and time periods are sometimes used as well. There are thus considerable uncertainties associated with this method. Meyer and Sommer summarised employment factors from an assessment of peer-reviewed studies on renewable energy employment, shown in Table 3.

Value chain analysis

A tool that is based on value chain analysis can analyse various economic aspects and answer the following questions: Where can employment be generated? Where can the greatest revenues be attained? Where is there a significant dependence on foreign inputs along the supply chain?

Table 3: Employment factors for photovoltaics and wind power

		Region	Year of publication	Source
Photovoltaics				
Jobs/GWh	1.03	USA and Europe	2012	Lambert and Silva
	1.09	GRE	2011	Tourkolias and Mirasgedis
	0.87	USA	2010	Kuckshinrich et al.
Jobs/MW	38	Aragon (ESP)	2010	Sastrea et al.
	29	ESP	2013	Llera et al.
	37.3	ESP	2008	Morena and López
	54.8	GRE	2013	Markaki et al.
	37–46	TUR	2011	Cetin and Egrican
	28.3	Middle East	2013	Neuwahl et al.
Wind power				
Jobs/GWh	0.2	USA and Europe	2012	Lambert and Silva
	0.33	GRE	2011	Tourkolias and Miradgedis
	0.17	USA	2010	Kuckshinrich et al.
Jobs/MW	13	IRE	2007	Dalton and Lewis
	10.74	BRA	2013	Simas and Pacca
	13.2	ESP	2008	Moreno and López
	8.3	Middle East	2013	Van der Zwaan et al.

Source: Compiled according to Meyer and Sommer (2014), p. 17; see also IRENA (2013).

The analysis is a small-scale, company-oriented approach and is not always suited to answering macro-economic questions at national level (IRENA and CEM, 2014). A value chain analysis depicts the hierarchy of supply chains and relationships between companies. Companies are identified for each hierarchical tier as well as based on data on production capacities and costs, labour and other inputs, turnover and production value. Using this method, direct and indirect effects on employment and added value are generated. The value chain analysis requires detailed information on companies and their interdependencies, including costs, sales, semi-finished products, imports and exports. Possible sources include company and expert surveys, as well as industry classification systems such as the North American Industry Classification System or the European Community's statistical classification of economic activities.

DTI (2004) analyses the role of the renewables sector for Great Britain, in particular Scotland. The study identifies those companies active in the industry and their position along the respective supply chain. The study points to gaps in existing supply chains and limitations for British industry. The value chain approach has also been applied to solar energy technologies in Tunisia (Borbonus et al., 2014). Hirschl et al. (2010) calculated the added value at community level in Germany based on value chains and developed the simulation tool WeBEE.

The value chain model is an ambitious approach that takes into account and measures the complexity of technologies and supply chains. Value chains need to be documented extensively, and cost structures need to be specified (IRENA and CEM, 2014). The data requirements are therefore quite high.

Gross input-output

Cost-based input-output models are applied to assess (1) the direct gross value creation and employment in the renewable energies industries and (2) the indirect economic and employment effects brought about by the renewable energies industry in the rest of the economy; (3) the IO model can also be used to calculate induced and trade-related effects (Breitschopf et al., 2011).

The input-output method is more comprehensive than the approach based on employment factors, as it describes the relationships between the different industries in an economy and shows how the output of one sector can become the input of another. It combines technical economic data with input-output modelling. The starting point for the calculation of employment factors is the installed capacity and electricity production of renewable energy installations in the respective year.

For each specific technology there is a determination of specific installation costs, operating and maintenance costs, fuel costs per unit or energy output. Multiplied with the installation capacities, this gives us annual investment expenditures, operation and maintenance (O&M) expenditures and expenditures for biogenic fuels. The costs are then distributed across cost components (e.g. for PV modules, inverters and other operating equipment). These are assigned to the supply industries and depicted as in the input-output model. At the cost component or industry level, import shares are specified, which indicate the share of goods or services supplied from outside of the country or from the region being examined (Breitschopf et al., 2011).

National input-output tables, published by statistical authorities in many countries, are a key data requirement for this method. This can be a problem in countries where input-output tables are not sufficiently differentiated by sector. Adapting the data from other countries can be considered, even if this does not reflect the unique economic structure of a country. As the renewables industry encompasses cross-sectoral economic activities, developing technology specific input-output tables would be useful. Employment factors are sometimes published in conjunction with input-output tables and are useful supplements to the analysis. An example is Lantz (2009) with the JEDI model.

It is important to take foreign trade into account in the gross approaches described above (IRENA, 2016). In addition, it is often necessary to make assumptions on exports and imports of RE technologies. Import shares of installed installations represent lost opportunities for local equipment production. When impact assessments are based on investment and imports are not taken into account, the investment-based effects on manufacturing are overestimated. The findings are also influenced by productivity levels of labour and capital. Higher labour productivity requires a lower number of jobs.

Table 4 shows a comparison of these three approaches.

Gross Approach	Employment Factors	Gross Input-Output Models	Supply Chain Analysis
Key variables	▪ Employment only ▪ Only direct jobs in the RE industry	▪ Employment and other economic impacts (value added) ▪ Covers inderect jobs in upstream industries	▪ Macro/business perspective ▪ Direct and indirect employment and value chain
Applicability	▪ Quick assesments and simple monitor-ing of employment in the RE industry	▪ Medium to high, depending on data quality	▪ Quantification of eco-nomic value creation at a project or company level
Recources needed	▪ Low (if employment factors are easily available) to high (if they have to be derived)	▪ Medium	▪ High (significant detail needed on comparies within the value chain and their relations)
Critical Assumptions/ data require-ments	▪ Imports (domestic production), exports, labour productivity, labour input by RET ▪ Need to disaggregate data per RE techno-logy	▪ Imports (domestic production), exports, labour productivity, labour input by RET ▪ Static input-output tables assume no change in eco-nomic structure	▪ Imports (domestic production), exports, labour productivity, labour input by RET ▪ If Results want to be extrapolated to national level, assumptions about equal value chains

Table 4: Comparison of gross methods for assessing socio-eco-nomic effects

Source: IRENA and CEM (2014), p. 87.

Within the context of this paper no further discussion of calcu-lation tools for the assessment of socio-economic effects is possible. A comparison of tools can be found in IRENA and CEM (2014).

5.2 Net methods

Net input-output methods

Effects on the whole economy can be analysed by net-input-output methods. The analysis comprises induced effects such as changes in consumption, for example in the case that renewable energies lead to increased income, and thus to higher expenditures for goods and services. Furthermore, net job effects or job losses in other sectors can be assessed (Breitschopf et al., 2012). Net input-output methods depict how goods and services are handled in production sectors (IRENA and CEM, 2014). The primary difference between the net and the gross input-output approaches consists of the comparison of two scenarios, a reference or business-as-usual scenario on the one hand and a scenario with ambitious deployment of renewable energies on the other. The same data requirements exist as for the gross approach, in addition to further statistics for induced effects (e.g. electricity and CO_2 prices) as well as for the reference scenario. Case studies are Markaki et al. (2013) for Greece, and Okkonen and Lehtonen (2016) using regional input-output modelling.

This method has only limited suitability for analysing structural economic changes and dynamics, as it is based on input-output tables that provide a static picture of a national economy. The model does not take into account the impacts of electricity price changes, international trade and important economic actors such as households and governments. This makes the approach less resource-intensive than other net modelling methods.

Macro-econometric models

Sectorally disaggregated macro-economic models, based mainly on advanced statistical methods, are best suited for prospective short to medium range economic impact assessments. They are not based on neoclassical assumptions (perfect markets, complete rationality and optimised behaviour) but rather on the assumption that historically observed relationships will remain realistic in the future as well.

Macro-economic models include households, the public sector and international trade. Price-based interactions are also introduced through econometric relationships based on historically observable data.

They follow a post-Keynesian approach. These models require long-range time series data for assessing parameters and making model specifications, as well as significant knowledge of advanced statistical methods. This increases resource intensity and costs. These time series are often available in OECD countries. Case studies include Bukowski et al. (2013) on Poland; Lehr et al. (2012b) on Germany; European Commission (2014); Pöyry Management Consulting and Cambridge Econometrics (2014) on Ireland.

Macro-economic models have several strengths. For one, they can depict the imperfections of an economy. However, this aspect can also turn into a weakness, as past relationships do not necessarily remain the same in the future (e.g. changes in the economy through major technological innovations). The models do not adequately depict the micro-economic structure of the economy and, from a macro-economic standpoint they tend to show the benefits of renewable energy policies in a slightly more positive light (Meyer and Sommer, 2014).

Computable General equilibrium models (CGE)

Computable general equilibrium models (CGE) cover the same areas as macro-economic models. However, they are based on neoclassical assertions on perfect markets, complete rationality and optimised behaviour.

CGE models can, as a supplement to net input-output models, depict the entire economy including households, government, international trade as well as interaction between these areas. The development and application of CGE tools requires significant data input and modelling expertise. To a certain point, parameters can be derived from input-output tables. Additional data sources include national accounts, balance of payment and trade. With respect to case studies, CGE models have been applied in many countries for the assessment of the value creation potentials of renewable energies, e.g. Böhringer et al. (2013); Dannenberg et al. (2008) on the EU; Kes (2012) on South Korea).

CGE models are suitable for assessing long-term impacts that give economic actors sufficient time to adapt – under the assumption that no significant structural changes take place in the national economy. Their strengths lie in the solid micro-economic foundation, which allows considerable flexibility in the assessment of impacts of different policy measures, at regional level as well. The weaknesses of CGE models lie in their neoclassical assumptions (rational, perfect information and the assumption that markets always attain equilibrium situations). Larger structural economic changes cannot be depicted.

Economic simulation models

Economic simulation models complete net-input-output models by depicting the whole economy including households, government, international trade, investments and all interactions between them (IRENA und CEM, 2014). They are especially useful for assessing unexpected consequences of a certain policy.

Balancing inputs and outputs on the goods and service markets is represented by a system of supply and demand equations. Simulation models are based on neoclassical assumptions of optimising economic actors, perfect information and efficient markets. Data requirements are high and modelling expertise is required, which is why the models are highly resource-intensive. An example is Ragwitz et al. (2009) on the EU-27.

Economic simulation models are suitable for long-term assessments. Even if compared to other approaches they are less commonly used to assess the economic impacts of regenerative energies. Due to their complex structure, there are high costs associated with such studies. The micro-economic foundation of the models allows sufficient flexibility to apply the method to a regional level as well, even if time scales are not continuously available.

A comparison of net methods is provided in Table 5.

5.3 Attributing value to all observed impacts

Measuring the different types of indicators is challenging. Thus multiple benefits are sometimes listed but rarely quantified (Ürge-Vorsatz et al., 2014). When monetisation is not possible, non-monetary quantitative values can be used to factor socio-economic impacts into the standard methodologies alongside data on kilowatt hours and tons of carbon-equivalent saved. Where benefits remain unquantifiable techniques have been adapted to obtain a clearer qualitative measure of how the impacts are experienced by the beneficiaries. Most techniques can be categorized within the ranges of either quantitative or qualitative, and subjective or objective (see Figure 3).

		Comprehensive Economic Models (All Economic Secrors)		
Net Approach	Net Input-Output Modelling	Macro-Econometrics	Compitable General Equilibrium (CGE)	Economic Simulation
Key variables	▪ Medium data requirements; very limited dynamics	▪ Assumed relations require time-series data for parameteri-sation	▪ Assumptions of optimising agents and perfect markets	▪ Complex structures with many feedback loops
Applicability	▪ Rough net assesement for the short term	▪ Short-to-medium-term assesements	▪ Long-term assessements	▪ Long-term assessements
Recources needed	▪ Medium to high	▪ Very high	▪ Very high	▪ Very high
Critical Assumptions/ data require-ments	▪ Imports (and hence domestic production), exports, labour productivity, labour input by RE ▪ Development of economic and demographic growth, energy effency, fossil fuel prices, RE generation costs and CO_2 prices			

Table 5: Comparison of net methods for assessing socio-economic effects

Source: IRENA and CEM (2014), p. 92.

An overview of calcula-tion tools can be found in IRENA and CEM (2014).

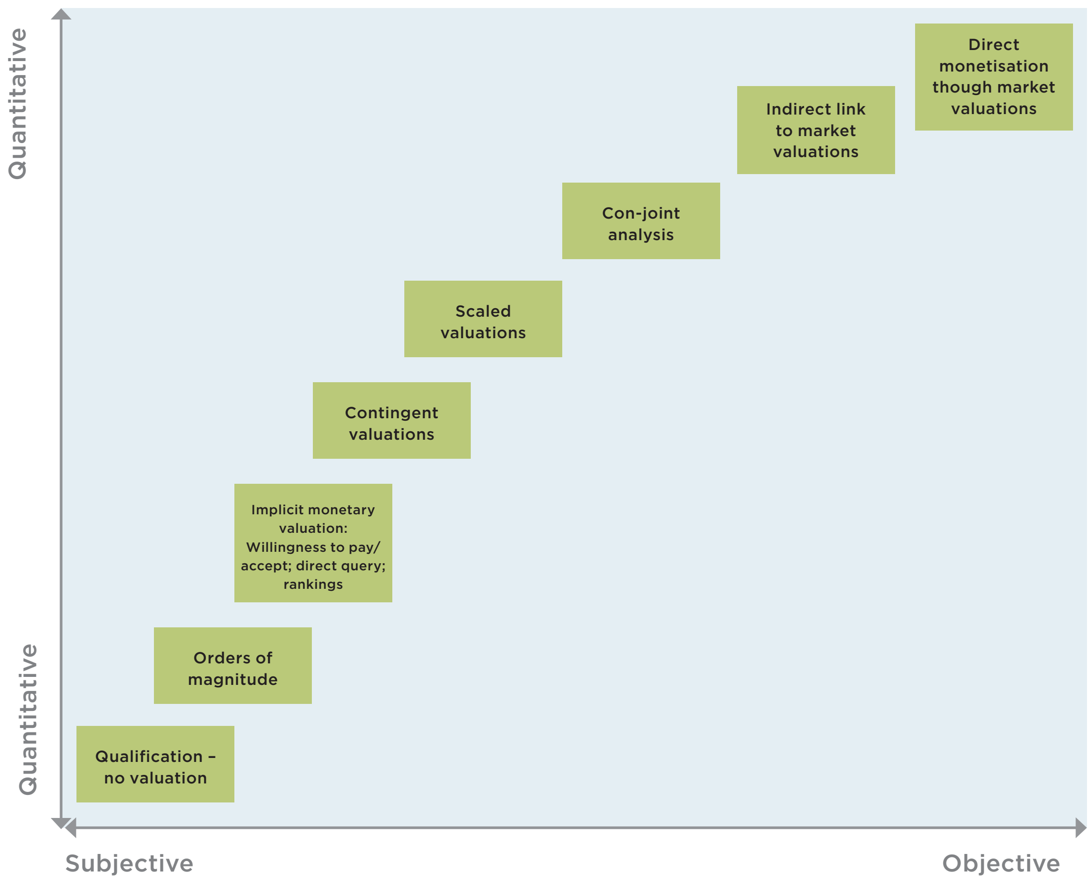

Figure 3: Methods to monetise socio-economic impacts

Source: IEA (2014), p. 193.

The most robust methods include direct linking to a market valuation (direct market values specific to each consumer, investor or beneficiary group) or calculating an indirect market valuation (e.g. valuing labour at current and anticipated market prices or valuing health benefits at prevailing applicable health services costs) (IEA, 2014). Social benefits cannot easily be attributed a fixed market value. Less objective techniques include willingness to pay and willingness to accept techniques can be used. The stated preference approach refers to quantification that derives from surveying beneficiaries about the value they would place on a certain outcome – a hypothetical choice in a hypothetical market. Conjoint techniques involve asking respondents to rank benefits, then applying econometric techniques to identify the 'utility' value of the outcomes, which can then be monetized. Direct query or choice experiment methods are even more subjective in that respondents are simply asked to put a value on the benefits. An orders of magnitude approach asks participants to make a relative valuation of several possible outcomes. Some socio-economic impacts do not lend themselves to quantitative assessment, e.g. impacts related to participation in decision-making procedures, improved inclusion or greater equity. Methods for measuring include case studies, focus groups, systemic interviews and surveys. Where quantification is not practical, experts advocate for triangulation of evidence from mixed methodologies.

6. Structuring a robust analysis

Which method is most suitable for which question? Before the appropriate analysis tool can be selected, several steps must be taken:

- Determination of what to assess: what kind of renewable energy policy, renewable energy target or scenarios; comparison of different renewable energy policies; ex-post or ex-ante policy evaluation

- Definition of the socio-economic variables to be examined (employment, GDP etc.) and the dimensions (gross or net; global, regional, national or sub-national; optimised or simulated; bottom-up or top-down)

- Selection of a method and a tool to generate the required results; verification of data situation and access to expertise as well as financial and time resources

It is initially necessary to clarify what exactly has to be assessed, e.g. the development of the renewable energy sector so far (ex post), the impacts of a certain policy to promote renewable energies or the impacts of different energy scenarios (ex ante). Secondly, it is necessary to select the socio-economic benefits that are to be quantified and, if applicable, to be monetised as variables. The analytical framework presented in Chapter 4.2 can provide support in making the selection. In a second step, the characteristics of the variables must be more closely defined: Are net or gross effects to be examined, i.e. the impacts of the expansion of renewable energies on the overall economy or only within the renewables sector (sectoral range)? What is the geographical range that is selected (global, regional, national or sub-national)? Benefits can come about at different levels (trickle-through effect) and should be examined separately (IEA, 2014). The technological approach comprises top-down or bottom-up modelling approaches. Bottom-up approaches are suitable if, for example, the value creation effects of a certain technology are to be assessed, e.g. wind power, while top-down approaches are more suited to a cross-technology analysis. 'Simulation' and 'optimisation' are mathematical techniques. Simulation models attempt to depict reality and simulate how economic actors interact with each other, while optimisation models present the best way to attain a certain objective.

Additional selection criteria are based on the following questions: To what extent does a tool allow for feedback loops between the energy sector and the economy? To what extent is innovation and its connection to technology costs and labour productivity depicted? To what extent are the complexities of human behaviour depicted in conjunction with the adoption of new technologies and reaction to certain policies (IRENA and CEM, 2014)? In addition to the selection of tools, further aspects are important for a robust analysis, including scenario design, the definition of system boundaries and sensitivity analyses (Mai et al., 2013).

A thorough analysis of socio-economic benefits should be based on an understanding of the welfare effects of the respective policy. However, such an analysis is time-consuming and costly, especially in developing countries where policy fields are not always clearly distinguished from each other. Determining the net welfare effect does not always have to happen at quantitative level. The precise scale is not always needed (Ürge-Vorsatz et al., 2014). The trend of an effect can already have a positive influence on policy decisions. For example, low levels of air pollution in developing countries definitely lead to positive net results.

7. Summary of findings and future research needs

Socio-economic values of renewable energies can be defined as economic activities with societal value along the value chain of renewable energy technologies. The values are characterised as follows: They can be generated at different levels (national, regional, local). They are additionally generated by supporting activities such as R&D and financial services. The effects can be direct, indirect or induced. They can be assessed as gross (positive) or net (positive or negative) effects. Socio-economic values of renewable energies are seldom measured, quantified and monetised.

The different socio-economic dimensions of renewable energies are not yet systematically analysed at international level. There are different approaches to analysing socio-economic effects of climate mitigation measures in general and renewable energies in particular. Aspects relevant to emerging and developing economies such as access to energy, rural development and health impacts have not been sufficiently considered. The analytical framework proposed in this discussion paper intends to go beyond mainstream dimensions and consider specific questions in emerging and developing economies. The analytical framework supports the selection of socio-economic dimensions by providing for a broad typology that allows further differentiation into sub-categories.

Generally speaking, gross and net methods can be applied in order to analyse direct, indirect and induced socio-economic effects. The methodologies vary considerably in terms of data and resource requirements. A robust analysis requires the identification of the variables to be analysed, the selection of an appropriate methodology as well as the verification of access to data and expertise. The analysis of socio-economic effects of renewable energies has to be adapted to different country perspectives and support their respective economic and social development goals.

Mayrhofer and Gupta (2016) point out that, in order to take structural changes into account, political realities should be included in the analysis of the effects of renewable energies. Helgenberger and Jänicke (2017, forthcoming) argue that in order to mobilise particular interests associated with the socio-economic benefits of renewable energies, respective (co-benefit) assessments need to focus on concrete, near-term benefits for relevant actors on the ground. The analytical approaches so far have been very oriented toward economics, with a focus more on incremental changes. An approach that seems promising is the linking of the co-benefits approach with the concepts of sustainable consumption and production. Okkonen and Lehtonen (2016), for example, examine the concept of 'social entrepreneurship' and the role of strategic re-investments in the development of renewable energies at regional level.

Despite the fact that many of the methods presented for assessing the socio-economic effects of RE expansion are available and well established, there is still need for further research. One proposal in IRENA (2016) for the continued development of the analytical framework consists of developing a dynamic approach to calculate changeable demand elasticity. More methodological considerations are still needed for the topic of access to energy and its macro-economic impacts. So far, there has been only insufficient study of structural and distributional effects in relevant sectors. A further research topic is the need to build capacity to accommodate the expansion of renewable energies. Researchers could develop an indicator for trade with "energy equipment" (see OECD and UNEP) in order to show the flow of trade and gain insight into localisation of value creation stages. Generally speaking, the analysis of socio-economic effects by renewable energies can be refined, for example by incorporating additional countries or new economic variables such as household income and consumption.

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