Online course

Co-Benefits Assessments: Methods and tools to identify and communicate social and economic opportunities of renewable energy

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renac
renewables academy

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1 Introduction: Quantification of co-benefits: Assessment methods

1.1 Learning objectives:

Upon completion of this course, you will be able to

- Develop causal chains for an assessment
- Interpret, communicate and commission methods for quantitative assessment of co-benefits
- Interpret findings of co-benefit analyses considering possible unwanted impacts and identifying the net-effects
- Identify indicators and data sources for quantification of key co-benefits (Jobs/employment, air pollution, health, energy access, local economic development, energy security)
- Commission and interpret co-benefit analyses and effectively communicate its results
- Prepare schematic cost-benefit analyses
- Interpret the findings of co-benefit analyses for re-formulating RE policies

1.2 Introduction: Quantification of co-benefits: Assessment methods

The course *"Co-Benefits Assessments: Methods and tools to identify and communicate social and economic opportunities of renewable energy"* provides an overview of how to conduct co-benefit assessments, presents methods used, introduces relevant impact areas, and suggests indicators for quantifying specific co-benefits.

The process of conducting co-benefits assessments follows a series of steps. The course focuses on steps 2, 3 and 4 of the overall assessment process and provides examples of application of the methods:

Figure 1: Process of a co-benefit assessment (Source: Adelphi, 2019)

Scoping phase

In the scoping phase, different types of impacts (direct, indirect, induced, gross/net effects) that may be relevant for the assessment are identified and it is determined for which impacts an in-depth analysis is necessary in order to assess their co-benefits.

In-depth analysis

Assessment methodologies for the in-depth analysis help to determine the likely extent of the previously identified effects. Tools that are frequently used to assess co-benefits include input-output data, computational equilibrium modelling, and distributional effects.

Comparison of options

Methods used for comparing policy options and their costs and benefits include cost-benefit analysis (CBA) and multi-criteria analysis (MCA). comparing. These help to compare different policy options and determine which one is likely to have the most co-benefits and may imply the highest costs or unwanted side-effects.

The assessment process and methodologies are introduced in chapters 2 and 3 of the course. To illustrate which co-benefits can be expected and which tools and methods are useful, chapter 4 demonstrates specific co-benefits in several impact areas (e.g. air pollution/health, employment, local economic development). Moreover, six country studies (India, Kenya, Mexico, South Africa, Trukey and Vietnam) complement the overview on how co-benefit analyses can be conducted. The course structure is illustrated below.

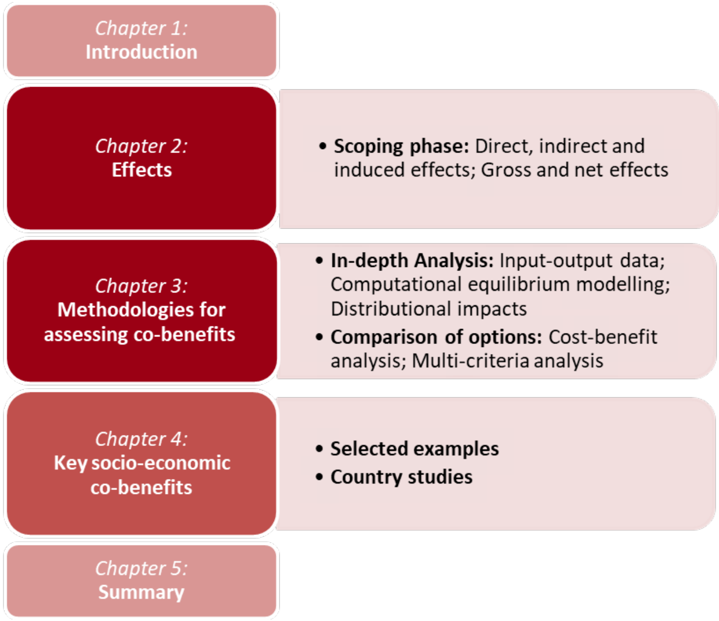

Figure 2: Structure of the course (Source: Adelphi, 2019)

1.3 Further readings:

<u>On impact assessment in general:</u>

There are several introductions and guidelines available to gain an overview of what impact assessment is, the general process and steps it follows, and which tools and methods can be used

- Dunlop, C.A., Radaelli, C.M. (ed.), *Handbook of Regulatory Impact Assessment*, 2016, Cheltenham: Edward Elgar Pub. Ltd.
- Morrison-Saunders, A., Pope, J., Bond, A., *Handbook of sustainability assessment*, Cheltenham, Edward Elgar Pub. Ltd, 2015.
- European Commission, *Better regulation*, 2015, available at: http://ec.europa.eu/smart-regulation/impact/index_en.htm.
- OECD, *What is impact Assessment?*, 2017, available at: https://www.oecd.org/sti/inno/What-is-impact-assessment-OECDImpact.pdf.
- Dunlop, C.A., Maggetti, M., Radaelli, C.M., Russel, D., 'The many uses of regulatory impact assessment: A meta-analysis of EU and UK cases', *Regulation & Governance*, Volume 6, p. 23-45, 2012.

There are also several studies available that have analysed how impact assessment processes are implemented in different countries (including the consideration of sustainability aspects in the assessment):

- Adelle, C., Weiland, S., 'Policy assessment: the state of the art', *Impact Assessment and Project Appraisal* 30 (1), 2012, pp. 25–33.
- Adelle, C. et al. 'Regulatory Impact Assessment - A Survey of selected and emerging economies', *LIAISE Discussion Paper*, 2014, accessible at: http://edocs.fu-berlin.de/docs/servlets/MCRFileNodeServlet/FUDOCS_derivate_000000004974/Regulatory_Impact_Assessment.pdf?hosts=.
- Jacob, K.; Ferretti, J.; Guske, A.-L.; Turnpenny, J.; Jordan, A. and Adelle, C., *Sustainability in Impact Assessments. A Review of Impact Assessment Systems in selected OECD countries and the European Commission*, OECD. SG/SD (2011)6/FINAL, 2012.

A data-base on published Impact Assessments can be found at the World Bank:

- World Bank, *Global Database for Regulatory Impact Assessment (RIA)*, accessible at: https://rulemaking.worldbank.org/en/ria-documents.

On co-benefits:

A review for comprehensive methodological guidance on the quantification of co-benefits:

- Ürge-Vorsatz, D.; Herrero, S.T.; Dubash, N.K.; Lecocq, F. 'Measuring the co-benefits of climate change mitigation', *Annual Review of Environment and Resources*, 39, 2014, pp. 549–582.

2 Effects

2.1 Scoping: direct, indirect and induced effects

Learning objectives: Upon completion of this page, you should be able to

- differentiate between direct, indirect, and induced effects
- recognise examples for immediate, long-term and spill over effects

To get a full picture of policy impacts beyond the intended effects, further unintended side effects need to be considered. Co-benefits do not occur as direct results of an intervention but as indirect or induced effects. For example, the following effects should be considered when building a factory for solar panels:

- **Direct effects**: these are primary effects, e.g. jobs created in the factory or value added. Direct effects may also include environmental effects, e.g. land use for the factory.
- **Indirect effects**: these are inputs needed from other sectors of the economy, e.g. construction industry, raw materials for the panels, energy for construction and running the factory etc. Besides economic effects, indirect environmental effects (e.g. reduced emissions from using solar panels instead of fossil fuels) could be considered.
- **Induced effects**: these are further secondary effects: by spending income from economic activities, demand for other goods and services is created which in turn causes economic, social and environmental impacts.

These effects can occur within different time frames (short-term/immediate, medium, and long-term effects). There is no scientific rule for distinguishing between direct, indirect, and induced or short- and long-term: a direct effect in one example can be an indirect or induced effect in another one. For example, new jobs in the solar industry can either be considered as direct effects of investments in renewable energies or as indirect effects with the construction of solar panel factories being the direct effect.

A result chain analysis can be used as a starting point for analysing different types of effects and determining their relevance [1]. Based on this first scoping exercise, it can be decided which effects need in-depth analysis. A simplified result chain is depicted in Figure 3 below.

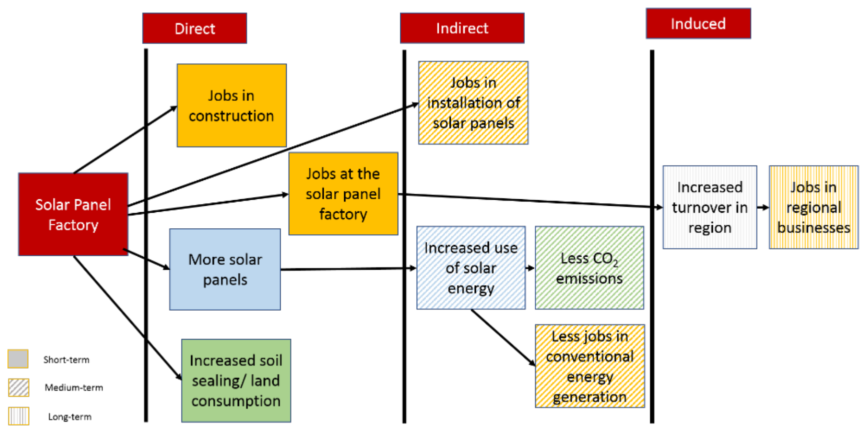

Figure 3: Example of a simplified result chain (Source: Adelphi & FFU, 2019)

2.2 Scoping: gross and net effects

Learning objectives: Upon completion of this page, you should be able to

- define gross and net effects
- explain negative/adverse effects
- identify indicators for gross and net effects (examples)

Generally, *gross effects* include all positive impacts, benefits or gains, while gross negative/adverse effects consider all negative impacts, costs or losses. *Net effects* are obtained by subtracting *negative* from *positive* effects [2–3].

$$Net\ effects = positive\ effects - negative\ effects$$

Net effects have a **positive** value if the benefits outweigh the adverse effects. Conversely, net effects are **negative** if the gains are inferior to the adverse effects.

For example, even PV solar systems lead to some greenhouse gas emissions (negative effects) during their entire lifetime. However, when replacing coal power generation, photovoltaics help avoiding significantly higher emissions (positive effects). Consequently, the net mitigation effect is positive.

In the **process of scoping**, considering gross and net effects helps to…

- identify impact areas and need for further assessment
- structure and organise the assessment [4]

Table 1 illustrates this. If only assessing job gains, option B seems more attractive. However, if the losses are considered, too, the relative best option is A.

	Option A	Option B
Gross number of jobs created	7	10
Gross number of jobs lost	-6	-11
Net job effect	1	-1

Table 1: Example for gross and net effect (Data source: World Bank, 2011)

As discussed before, effects can have different dimensions – they can occur in the short- or long-term, be reversible or irreversible and can appear at different levels (e.g. local, regional). Different types of effects cannot be simply added or subtracted. Moreover, being able to show that a proposed option causes the highest positive net effects, helps in legitimising policies [5].

2.3 Chapter endnotes

[1] Ferretti, J.; Guske, A.; Jacob, K. and Quitzow, R., *Trade and the environment. Framework and methods for impact assessment*, Forschungszentrum für Umweltpolitik: FFU-Report 5/2012, 2012.

[2] World Bank, *Issues in estimating the employment generated by energy sector activities*, 2011, retrieved from: http://siteresources.worldbank.org/INTOGMC/Resources/Measuring_the_employment_impact_of_energy_sector1.pdf

[3] Jacob, K.; Quitzow, R. and Bär, H., *Green Jobs: Impacts of a Green Economy on Employment*, 2015, retrieved from: http://www.greengrowthknowledge.org/sites/default/files/downloads/resource/Jacob%2C%20Quitzow%2C%20B%C3%A4r%202014%20Green%20Jobs_ENGLISH.pdf

[4] Ferretti, J., *Scoping*, 2014, retrieved from: http://www.liaise-kit.eu/ia-methods/scoping.

[5] 5 LIAISE, *Comparing and ranking the options*, 2012, retrieved from: http://www.liaise-kit.eu/ia-activity/comparing-and-ranking-options.

2.4 Further readings

GIZ has published a guidebook for practitioners on how to conduct policy impact assessments. It includes an in-depth overview of different methods for identifying direct, indirect, and induced effects:

- GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), *Planning Policy Impact Assessments and Choosing the right Methods – Manual for Development Practitioners*, Bonn, 2016.

Software applications that can be used for developing result chains:

- iModeler: http://www.consideo-modeler.de/Tutorial/MODELER-HELP/Wirkungsketten.html, you can download a free demo version here: http://www.consideo-modeler.de/download.html
- CmapTools: http://cmap.ihmc.us/

Appendix 1 of the World Bank report „Issues in estimating the employment generated by energy sector activities" published in 2011 provides details on how opportunity costs may affect the calculation of net effects:

- http://siteresources.worldbank.org/INTOGMC/Resources/Measuring_the_employment_impact_of_energy_sector1.pdf

The study "Levelized cost of electricity" by Fraunhofer Institute for Solar Energy Systems, published in 2018, provides recent data on the specific costs of energy technologies in Germany. Even though the costs may vary internationally, they can serve as a benchmark:

- https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/EN2018_Fraunhofer-ISE_LCOE_Renewable_Energy_Technologies.pdf

3 Methodologies for assessing/evaluating co-benefits

3.1 Introduction to modelling tools

Learning objectives: Upon completion of this page, you should be able to

- explain what makes model useful for analyses
- differentiate basic pros and cons of different modelling types

In the context of impact assessments, a model is a simplified and mathematical representation of a system (economic, technical, natural) for analysing scenarios on possible future states of the system. In the following, we focus on economic models as these are highly relevant for co-benefit analyses. They represent the economy as a whole or as single markets for assessing the impacts of policies.

Every model has to determine system boundaries. Models use empirical observations on causal relations or assumptions, e.g. on the behaviour of consumers, firms etc. The reliability of model outcomes depends on both the validity and appropriateness of system boundaries, assumptions, and observations. Every model is a simplification of reality. This fact is a feature rather than a failure: If a model was equal to reality, it would not be meaningful for analyses. The question is whether the simplification is justified for the respective purpose.

The tables below give an overview of different families of models and show which questions they can help to answer. In principle, all economic models can indicate environmental impacts if appropriate data is included (e.g. tons of GHG emissions per economic activity in material I-O table).

	Computational General Equilibrium (CGE)	Partial Equilibrium	Microsimulation	Econometric models	System Dynamics
Question/ Output	Economic-wide effects of a single impulse (e.g. policy)	Effects on single markets (in particular prices)	Employment and distributional impacts on firm/household level Returns from taxation	Employment, Economic wide effects (e.g. investments, prices, employment, value added): time series	Investments, Employment, Economic wide effects
Definition	Equitations to calculate a vector of prices under which all markets are cleared (=in equilibrium)	Representation of single markets	Disaggregation of an economy in smallest units (firms, households, etc.) to explore impacts on this level and to calculate aggregated total effects from decisions on the micro-level	Estimating changes based on observations and statistical inference	Representation of an economy as stocks and flows including feedback and explicit on time

Table 2: Overview of modelling types - definitions (Source: Adelphi, 2019 based on Rennings, K., 2013 and LIAISE Toolbox, 2015)

	Computational General Equilibrium (CGE)	Partial Equilibrium	Microsimulation	Econometric models	System Dynamics
Input requirements	Input-Output tables as data basis Elasticities capturing the expected behavioural response	Data for the economic activities for a specific sector Elasticities as behavioural parameters	Requires the use of detailed micro data from surveys or micro-level administrative data; e.g. on demographic, income and expenditure, taxes, etc.	Data in form of time series and observations on behavioural changes	Diversity of data sources, including I/O tables
Main advantages	Suitable for analysing structural changes as a result of a policy intervention Often ready-made databases exist. All data requirements can be replaced by assumptions	Helps assessing impacts on specific (groups of) commodity/-ies Relatively high degree of disaggregation and detailed representation	Suitable for analysis of distributional impacts	Time series, fewer assumptions as compared to CGE modelling, realistic representation of labour markets.	Particularly explicit on investments and employment Also usable for modelling stocks of knowledge

Table 3: Overview of modelling types - input requirements and main advantages (Source: Adelphi, 2019 based on Rennings, K., 2013 and LIAISE Toolbox, 2015)

	Computational General Equilibrium (CGE)	Partial Equilibrium	Microsimulation	Econometric models	System Dynamics
Main disadvantages	Assumptions are disputable (e.g. rationality of consumers) No/poor representation of labour markets. Small impulses cannot be meaningful modelled	No overview on indirect and induced impacts Does not consider feedbacks or interactions with other sectors	Data intense Lack of feedback to other parts of the economy	Particularly data intensive	Lack of consistent theory on causalities

Table 4: Overview of modelling types - main disadvantages (Source: Adelphi, 2019 based on Rennings, K., 2013 and LIAISE Toolbox, 2015)

3.2 Input-output data

Learning objectives: Upon completion of this page, you should be able to

- describe in which fields and for what purpose input-output data is used
- know where to find input-output tables (e.g. OECD, EU, in co-benefits partner countries India, Kenia, Mexico, South Africa, Turkey and Vietnam)

Input-output (I-O) tables contain data to analyse the interdependencies between different sectors or regional economies. The table depicts how an output from one sector becomes an input in another one (Figure 4).

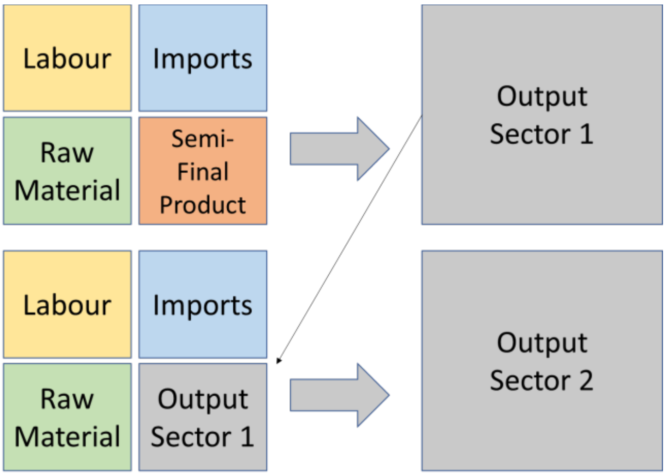

Figure 4: The input-output concept (Source: adelphi & FFU, 2019)

The main advantage of I-O tables is that they cover the entire economy. Results are used for structural analyses, including direct and indirect effects of changes in demand, prices, or wages, etc. This demonstrates impacts of a policy change and helps to identify co-benefits (e.g. a rise in demand, jobs, etc.) and indirect/induced effects (e.g. if jobs are created in another sector than the one addressed by the policy change). I-O tables can be used to draw a picture of supply chains within an economy.

Physical I-O tables account for flows of materials and energy. They can be used to assess environmental impacts resulting from economic activity.

I-O data is incorporated into national accounting for calculating national GDP and is used as input to modelling and simulation exercises. The availability of I-O tables depends on accessible data which is usually collected and published by national statistics offices. Usually, data is available for national economies. In some cases, there are regional I-O tables as well. Furthermore, national tables can be aggregated in international tables that allow a cross-border analysis.

The rows of the sample table in Figure 5 represent the distribution of a sector's output. The columns represent the amount of input an industry purchases from other sectors to produce its output:

Symmetric *industry-by-industry* IO table at basic price

	Intermediate demand			Final expenditure			Output (*bp*)
	Sector 1	…	Sector 34	Domestic demand	Cross-border exports	Direct purchases	
Sector 1 (domestic)						Expenditure by non-residents	
…							
Sector 34 (domestic)							
Sector 1 (imports, *bp*)		Imports of intermediate products		Imports of final products	Re-imports and Re-exports	Direct purchases by residents	
…							
Sector 34 (imports, *bp*)							
Taxes *less* subsidies on intermediate and final products							
Total intermediate / final expenditure (*pu*)							
Value added (*bp*)							
of which, Labour compensation							
of which, other value added							
Output (*bp*)							

(*pu*): purchasers' prices
(*bp*): basic price

Figure 5: Example of an I-O table (Source: OCDE Stat, 2011)

3.3 CGE modelling

Learning objectives: Upon completion of this page, you should be able to

- list the most relevant strengths and weaknesses of CGE modelling
- interpret the results of CGE modelling
- list the most relevant strengths and weakness of CGE modelling

Computational Equilibrium Modelling (CGE Modelling) is a tool to analyse impacts and structural responses of the economy to an external shock, e.g. a change in taxation. CGE models allow for the evaluation of direct, indirect and induced effects across countries and economic sectors.

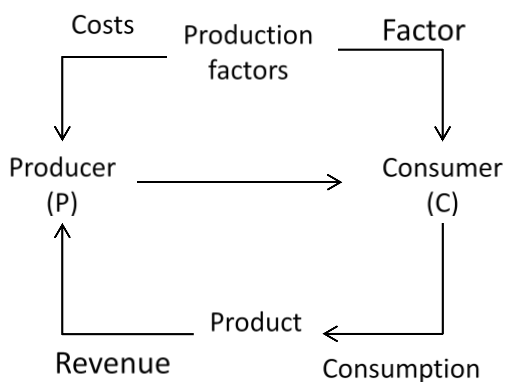

Figure 6: Simple CGE model (Source: adelphi & FFU, 2019)

The economy is represented as vectors of prices that clear the markets (equilibrium of supply and demand). An external influence is represented as an influence on prices which accordingly results in shift of demand, supply, and prices in other sectors. Markets can be represented in a simple way (see Figure 6). Usually, however, the representation of an economy is more sophisticated (see Figure 7).

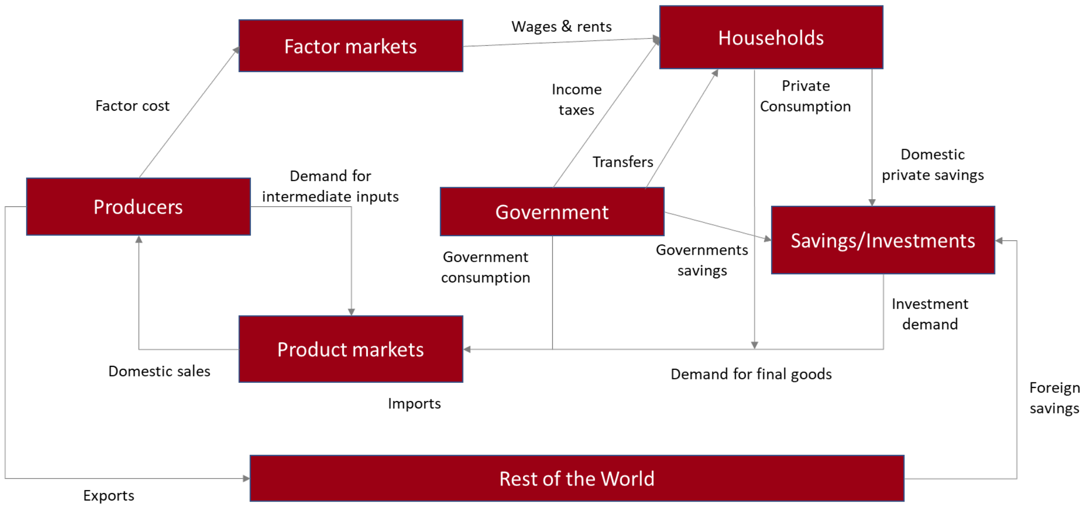

Figure 7: Complex CGE model (Source: adelphi & FFU, 2019 based on IADB, 2018)

Since CGE models represent the whole economy, they are less suitable for capturing smaller impulses than sectoral models [1]. Another critique is the representation of labour markets: As CGE models assume the clearance of markets and calculate prices until demand meets supply, they do not consider unemployment.

As CGE models are developed to account for indirect effects they can reveal co-benefits along the value chains. If physical input-output tables are used for CGE modelling, e.g. emissions of a sector, environmental impacts along the value chain can be evaluated as well.

A major advantage is their clear theoretical foundation. Based on this, missing data can be replaced by assumptions and CGE models can be constructed with very limited data requirements. However, the validity of the (neo-classical) theory and the assumptions can be disputed.

3.4 Distributional impacts

Learning objectives: Upon completion of this page, you should be able to

- describe what distributional impacts are
- know that policy design can reduce or increase existing inequalities

Policies affect population groups differently. For example, poor households spend a higher share of their income on energy and are therefore disproportionately more affected by (policy-induced) increases in energy prices [2]. The assessment of distributional impacts sheds light on the **scale** and the **direction** of such impacts and is thus a means to assess social and economic co-benefits of policies to promote renewable energy.

Inequalities often arise between income brackets (example above), age classes, rural and urban population, genders as well as between industries like the renewable energy and the conventional energy sector.

Depending on the specific design, policies to support renewable energies can reduce or increase existing inequalities [3]. In the latter case, the anticipation of distributional impacts may result in mitigating measures like adjusting transfer payments [2–4].

It is common to scope possible impacts via causal chains (see Figure 8) and to validate them with empirical research or modelling. The latter helps to forecast how different households respond to change.

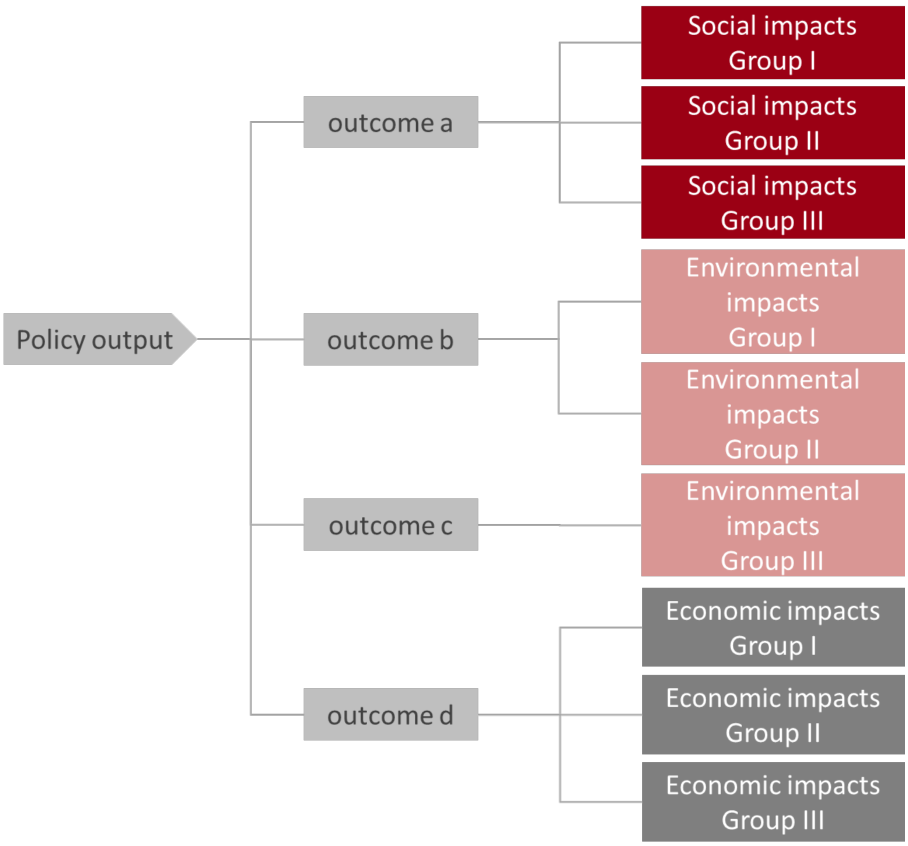

Figure 8: Causal chain for scoping distributional impacts (Source: adelphi & FFU, 2019 based on Jakob, K et al., 2016)

Some guiding questions for assessing distributional impacts are:

- What are the provisions of the policy (policy outputs)?
- How will the policy be implemented (outcomes)?
- What are the social, ecological or economic impacts on different population groups or industries and do these impacts correspond with the policy target?

3.5 Cost-benefit analysis

Learning objectives: Upon completion of this page, you should be able to

- know the aspects that need to be considered in a cost-benefit analysis
- understand the necessary steps to perform a schematic cost-benefit analysis

When assessing co-benefits, it needs to be determined whether the benefits will outweigh the costs of a planned initiative. The cost-benefit analysis (CBA) is one of the most often used methods to compare advantages (benefits) and disadvantages (costs) resulting from a new policy.

Firstly, it is necessary to identify all possible costs and benefits associated with the proposed policy.

Secondly, a monetary value is assigned to each type of cost and benefit. Typically, different categories of costs are included: resource costs (all resources needed to implement the policy), compliance costs (all resources needed for complying with the policy), regulatory costs for the government, social welfare gains/losses, transitional costs, and indirect costs. [5] For some categories, it is hard to assign a monetary value. For example, there are attempts to monetise health benefits, which are already widely accepted, but for biodiversity the attempts for monetisation are disputed. In other cases, monetising is hardly possible at all (e.g. measuring quality of life).[1]

Thirdly, costs and benefits are aggregated to get total sums. This can be challenging as the costs and benefits may occur in different time periods (short-, medium-, and long-term impacts). In these cases, discounting them (thus, applying the discount rate) is necessary to compute their present value. Moreover, CBAs do not consider distributional impacts or intergenerational fairness.

If all relevant costs and benefits have been collected and aggregated, it can be assessed whether the benefits outweigh the costs. If this is the case, CBA suggests implementing the policy. If alternative policies are compared, CBA recommends choosing the option with the largest net benefits (defined as benefits minus costs). [6] [7]

[1] In those cases, where monetising is not possible at all, a Multi-Criteria Assessment (see 3.6) rather than a CBA should be used.

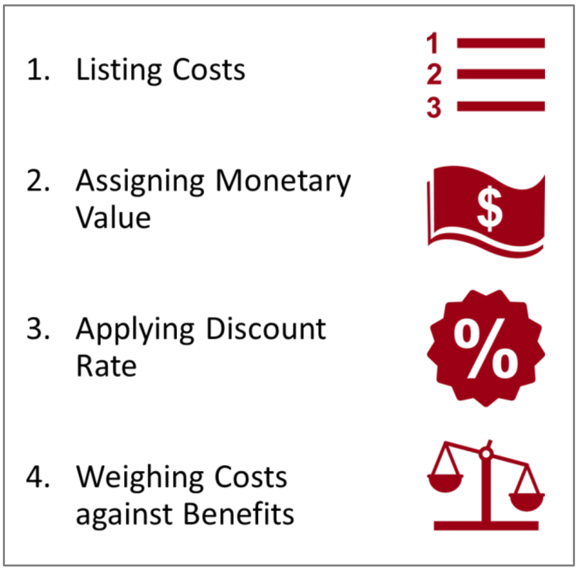

Figure 9: Ideal-type steps of a cost-benefit analysis (Source: adelphi & FFU, 2019)

3.6 Multi-criteria analysis

Learning objectives: Upon completion of this page, you should be able to

- know how multi-criteria analyses can help find the best policy alternative
- understand the elements of an evaluation matrix
- interpret the results of a multi-criteria decision analysis

A multi-criteria analysis (MCA) is a method for comparing different policy alternatives and determining which option is likely to have the greatest benefits. Aggregation and comparison are necessary when the findings of the in-depth analysis cover many different aspects and dimensions, e.g. impacts on emissions, employment, income, taxes etc.

Usually, the starting point is to set up an evaluation matrix. It contains criteria for evaluating the policies. The scores of these criteria can be expressed in different units (monetary, bio-physical, etc.). To be able to compare the costs and benefits expressed in these different units, a value according to some sort of fixed value scale needs to be assigned to each criterion. There are different approaches for developing the value scale. The scale can be numerical (0-1), symbolic- (+, -) or colour-coded (red, yellow, green). The scale shows whether a criterion is considered a benefit or a cost. When values and weights are assigned, the criteria can be aggregated. The most often applied way is to translate the scores into a numerical scale and multiply each score with the respective weight. In the end, all weighted scores can be summed up. This is called the weighted linear combination. [8]

However, there are other aggregation methods that can be distinguished by the type of data used and the decision rule. Decision rules can be compensatory or not, meaning that benefits in one impact area can offset costs in another one (or not). There is software available that can support MCAs. Moreover, a sensitivity analysis can be used to determine the robustness of the aggregation. Such methods can be combined with Delphi surveys [9] and stakeholder analyses to increase the robustness of the assessment.

Scale:
++ = very positive impacts
+ = positive impacts
0 = no impact
- = negative impact
-- = very negative impact

Policy Options

	Subsidy for renewable energies	Tax on energy consumption
Job in RE sectors	++	+
Costs for poor households	0	--
Administrative burden	-	--
Government savings	-	++
GHG emissions	+	++
...		

Criteria (derived from policy objectives and relevant impact areas)

Scores (based on the results from the in-depth analysis, e.g. modelling exercises)

Figure 10: MCA based on a symbol scale (Source: adelphi & FFU, 2019)

Weight of each criterion based on importance of each impact in that particular case

Policy Options

	Subsidy for renewable energies	Tax on energy consumption
Job in RE sectors (weight 0,3)	2 (*0,3)	1 (*0,3)
Costs for poor households (Weight 0,5)	0 (*0,5)	2 (* 0,5)
Administrative burden (weight 0,2)	-1 (*0,2)	-2 (*0,2)
Government savings (weight 0,2)	-1 (*0,2)	2 (*0,2)
GHG emissions (weight 0,3)	1 (*0,3)	2 (*0,3)
...		
Sum	0,5	1,9

Sum of weighting (assuming that compensation is possible)

Criteria (derived from policy objectives and relevant impact areas)

Scores (based on the results from the in-depth analysis, e.g. modelling exercises)

Figure 11: MCA based on a numeric scale including weighting of the different criteria (Source: adelphi & FFU, 2019)

3.7 Chapter endnotes

[1]: Author's own depiction based on: IADB, *Understanding a Comutatuional General Equilibrium Model*, retrieved from: http://www.iadb.org/en/topics/trade/understanding-a-computable-general-equilibrium-model,1283.html.

[2]: Jacob, K.; Guske, A.-L.; Weiland, S.; Range, C.; Pestel, N. and Sommer, E., *Verteilungswirkungen umweltpolitischer Maßnahmen und Instrumente*, 2016.

[3]: Douenne, T., 'Les effets redistributifs de la fiscalité carbone en France', *Les notes de l'IPP,* 2018.

[4]: Neuhoff, K.; Bach, S.; Diekmann, J.; Beznoska, M. and El-Laboudy, T., 'Steigende EEG-Umlage: Unerwünschte Verteilungseffekte können vermindert werden', *DIW Wochenbericht,* 2012.

[5]: Arampatzis, S., *Cost-benefit analysis*, *LIAISE KIT*, 2013, available from http://www.liaise-kit.eu/ia-methods/cost-benefit-analysis.

[6]: Ferretti, J. et al., *Trade and the environment. Framework and methods for impact assessment*, 2012, Forschungszentrum für Umweltpolitik: FFU-Report 5, 2012, pp. 88ff.

[7]: GIZ, *Planning Policy Impact Assessments and Choosing the right Methods – Manual for Development Practitioners*, Bonn, 2016.

[8]: Geneletti, D., *Multi-criteria analysis*, *LIAISE KIT*, 2013, available, from http://www.liaise-kit.eu/ia-methods/multi-criteria-analysis.

[9]: Slocum, N., *Participatory methods toolkit - A practitioner's manual*, 2003, United Nations University, available from: http://archive.unu.edu/hq/library/Collection/PDF_files/CRIS/PMT.pdf

3.8 Further readings

Further readings for screen page 3.1:

An overview of modelling in the context of trade is available from the World Trade Organization. Many of the techniques are also relevant and applicable in other contexts:

- World Trade Organization, *A practical Guide to Trade Policy Analysis*, accessible at: http://vi.unctad.org/tpa/.

The LIAISE-Toolbox provides an overview of different methods and modelling types, but also concrete models and examples of their application:

- www.liaise-kit.eu.

A comparison of model types used in assessing the impacts of climate and energy policy:

Huppmann, D. and Holz, F., *Modelling the impact of energy and climate policies*, 2014, DIW Round up, accessible at:
http://www.diw.de/de/diw_01.c.488399.de/presse/diw_roundup/modelling_the_impact_of_energy_and_climate_policies.html

Further readings for screen page 3.2:

I-O tables of OECD members in OECD statistics database:

- OECD.Stat, *Input Output tables,* accessible at: https://stats.oecd.org/Index.aspx?DataSetCode=IOTS.

EuroStat I-O tables for EU member states:

- Eurostat, *ESA Supply, use and Input-output tables*, 2010, accessible at: https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/data/database.

I-O tables for South Africa:

- Stats SA, *Economic Analysis. Input-output tables for South Africa, 2013 and 2014*, accessible at: http://www.statssa.gov.za/publications/Report-04-04-02/Report-04-04-022014.pdf.

I-O tables for Vietnam:

- General Statistics Office of Vietnam, *Statistical Handbook 2011*, accessible at: http://www.gso.gov.vn/default_en.aspx?tabid=490&ItemID=1817.

I-O tables for Kenya:

- The Kenya Institute for Public Policy Research and Analysis, *An Input-Output Table for Kenya and its Application to Development Planning*, 2017, accessible at: https://kippra.or.ke/index.php/publications?task=download.send&id=28&catid=5&m=0

I-O tables for India:

- Ministry of Statistics and Programme Implementation, *Input Output Transactions Table 2007-08*, accessible at: http://mospi.nic.in/publication/input-output-transactions-table-2007-08

I-O tables for Turkey:

- Turkish Statistical Institute, *Input-Output Tables*, accessible at: http://www.turkstat.gov.tr/Start.do

Physical I-O tables:

- WIOD, *Environmental Accounts (for India and Turkey; including energy use, CO_2 emissions and air pollutants)*, 2013, accessible at: http://www.wiod.org/database/eas13.
- Exiobase (including raw materials and types of water uses), accessible at: https://www.exiobase.eu/index.php/about-exiobase

Further readings for screen page 3.3:

For an in-depth explanation of how CGE models work, Christoph Böhringer et al. give a detailed overview of CGE models and show in which context they are useful for non-technical readers:

- Böhringer, C; Rutherford, T. F. and Wiegard, W., Co*mputable General Equilibrium Analysis: Opening a Black Box,* ZEW Discussion Paper No. 03-56, 2003, accessible at: http://ftp.zew.de/pub/zew-docs/dp/dp0356.pdf.

Sue Wing provides a detailed explanation of how CGE modelling works by describing the approach for decision makers and other non-experts in this particular field:

- Wing, I. S., *Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis: Everything You Ever Wanted to Know (But Were Afraid to Ask)*, 2004, accessible at: http://www.rri.wvu.edu/CGECourse/Sue%20Wing.pdf.

For a more academic-oriented, technical overview on CGE modelling, the book by Mary Burfisher is helpful to better understand how CGE models work:

- Burfisher, M., *Introduction to Computable General Equilibrium Models*, Cambridge University Press, 2012.

Lofgren et al. give an overview of the Software GAMS, which is open source and can be used for CGE modelling:

Lofgren, H. et al., *A Standard Computable General Equilibrium (CGE) Model in GAMS*, 2012, accessible at: http://www.un.org/en/development/desa/policy/mdg_workshops/training_material/lofgren_lee_and_robinson_2002.pdf

Further readings for screen page 3.4:

The OECD report "Understanding the distributional and household effects of the low-carbon transition in G20 countries" published in 2017 contains further advice on how to measure distributional impacts. Moreover, it discusses typical distributional impacts of selected policy instruments and deals with measures to effectively mitigate negative distributional impacts.

- https://www.oecd.org/environment/cc/g20-climate/collapsecontents/McInnes-distributional-and-household-effects-low-carbon-transition.pdf

For advanced readers: A study published in 2018 by Thomas Douenne uses microsimulation (see introduction to modelling) as a method to assess the impacts of the French carbon tax quantitatively. Thus, the author draws the attention to distributional impacts, e.g. *within* income groups and *across* regions (see chapter 6.3).

- https://www.ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/resource-econ-dam/documents/research/sured/sured-2018/23-DOUENNE-The_vertical_and_horizontal_distributive.pdf

The LIAISE Toolbox is a library of models, publications, projects, good practices, experts, etc. to support policy impact assessments. Find more information on distributional impacts here:

http://www.liaise-kit.eu/impact-area/distributional-impacts

Further readings for screen page 3.5:

Pearce and Atkinson provide an overview of the origins, basic concepts, and possible applications of CBA in the context of environmental policy:

- Pearce, D.; Atkinson, G. and Mourato, S., *Cost-Benefit Analysis and the Environment*, Paris, OECD, 2006.

Mishan and Quah provide an overview of different areas of application of CBA and describe how CBA was applied in various case studies:

- Mishan, E. and Quah, E., *Cost-Benefit Analysis*, London, Routledge, 2007.

The transportation economics committee looks at applying CBA in the context of transportation and infrastructure policies. However, their information and guiding questions are useful and applicable in other contexts as well:

- Transportation Economics Committee, *Benefit-Cost Analysis*, accessible at: http://bca.transportationeconomics.org/home

For more information on how to conduct a CBA using spreadsheets, Campbell and Brown provide an in-depth overview:

- Campbell, H. and Brown, R., *Benefit-Cost Analysis: Financial and Economic Appraisal Using Spreadsheets*, Cambridge University Press, 2003.

Further readings for screen page 3.6:
For an overview of different options for designing an MCA, different techniques, and options for combining it with other methods, see:

- Department for Communities and Local Government, *Multi-criteria analysis: a manual,* London: 2009, accessible at: http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf.

The Joint research Centre of the European Commission has published an overview on MCA, including a framework, different methods, and visualisations:

- Joint Research Centre of the European Commission, *Multi-Criteria Analysis*, 2016, accessible at: http://forlearn.jrc.ec.europa.eu/guide/4_methodology/meth_multi-criteria-analysis.htm.

For a review on how MCA is applied in sustainable energy planning, Pohekar and Ramachandran provide an overview of applications in this context:

- Pohekar, S.D. and Ramachandran, M., 'Application of multi-criteria decision making to sustainable energy planning—A review', *Renewable and Sustainable Energy Reviews*, Volume 8, Issue 4, 2004, pp. 365-381.

Huang et al. analyse how MCA has been used in environmental sciences over the past years and point out trends and examples of application:

- Huang, I.B.; Keisler, J. and Linkov, I., 'Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends', *Science of The Total Environment*, Volume 409, Issue 19, 2011, pp. 3578-3594.

4 Key socio-economic co-benefits

4.1 Jobs and employment

Learning objectives: Upon completion of this page, you should be able to

- differentiate between direct, indirect and induced employment effects
- identify assessment tools to estimate employment impacts
- illustrate and effectively communicate employment impacts of renewable energy deployment

Dimensions

A policy may have direct, indirect, and induced employment effects. Gross effects account for jobs created by expanding renewables in various sectors as shown in Figure 12, while net effects also consider job losses e.g. in conventional energy sectors and their repercussions on indirect and induced employment. For example, by fully implementing its renewable energy targets, Mexico would create more than 375,000 direct and indirect job years by 2030 and more than 1 million direct and indirect job years by 2050 [1].

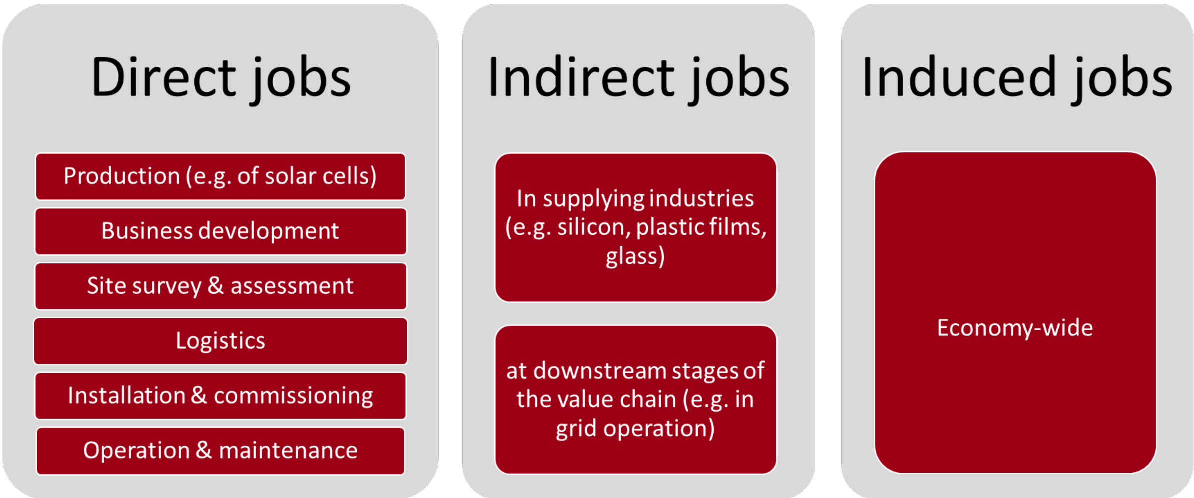

Figure 12: Multiplying employment impacts of renewable energy (Source: Fraunhofer Institute, 2016, SCGJ, 2016 and Jacob, K. et al., 2015)

We discuss two assessment tools:

1) **Employment factors** indicate the average labour used in *job-years* or in *full-time equivalent* (FTE) per capacity (in Watt or Watt-hour).
2) **Input-output (I-O) tables** are used to assess employment impacts based on the *level of spending* in a sector.

> Turkey is rapidly increasing its renewable energy capacity – in the ten-year period up to 2028, each additional MW in wind energy production would lead to an increased employment of 6.3 FTE workers across the entire value chain. Based on the current policies, until 2028 59,000 FTE jobs across the wind power value chain would be created. [2]

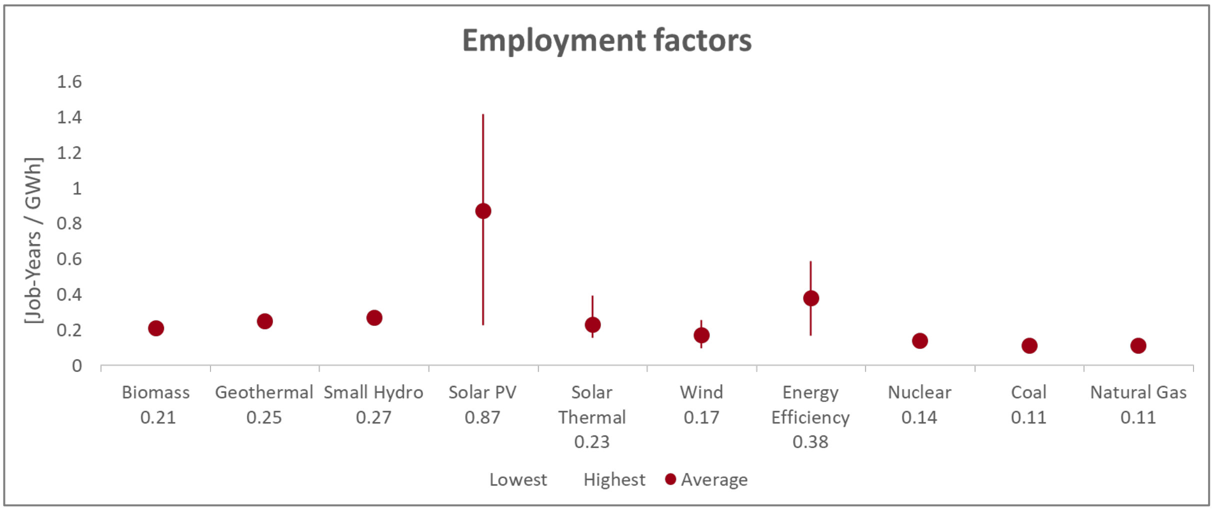

Figure 13: Direct job impacts by technology, US (Source: Wei, M. et al., 2010)

Figure 13 shows averages and ranges for *employment factors* of different technologies in the US. A small wind farm with an annual *generation* of 60 GWh would lead to 10 job years or FTE (*full-time equivalent)*. The same stimulus would only translate into 7 jobs in the coal industry. In India, the employment impact per installed capacity of renewable energy is about 25 times greater than fossil-fuel based power generation [3]. The calculation formula is:

$$\begin{aligned} &annual\ employment\ [job\ years] \\ &\qquad = powergeneration\ [GWh] * employment\ factor\ [job\ years\ per\ GWh] \end{aligned}$$

Apart from direct effects, I-O tables help to assess indirect and net effects. Applying I-O-tables requires defining the respective energy sectors and their relative input-output coefficients by splitting up the standard I-O-tables [4–5]. Assessing induced effects additionally requires to inquire incomes in the renewables sectors and general spending patterns [6].

Employment factors, I-O factors and typical **professions** or **skills** needed are usually identified via surveys.

4.2 Climate and environment

Learning objectives: Upon completion of this page, you should be able to

- illustrate how renewable energy mitigates greenhouse gas emissions and air pollution
- identify suitable indicators to quantify air pollution mitigation as a co-benefit of renewable energy
- effectively communicate benefits of decreased greenhouse gas emissions and air pollution as an impact of renewable energy

The combustion of fossil fuels does not only emit greenhouse gases such as CO_2, but also different air pollutants – substances in the atmosphere that put humans, animals, and vegetation at risk [7–8]. To compare their contribution, it is common to use the unit of CO_2 equivalents (e.g. methane has a CO_2 equivalent of 25, i.e. one tonne of methane has the same global warming potential as 25 tonnes of CO_2). Similarly, SO_2 equivalents facilitate the comparison of acid forming pollutants. A third indicator is the emission of particulates.

Pollutant	Name	Relative global warming / acidification potential	
Greenhouse gases	Carbon dioxide Methane Nitrous oxide	1 25 298	CO_2 equivalent
Acid forming pollutants	Sulfur oxide Nitrogen oxide	1 0.696	SO_2 equivalent
Other air pollutants	Particulates	-	-

Table 5: Selected greenhouse gases and air pollutants from burning fossil fuels (Source: German Environmental Agency, 2020)

Over their entire lifecycle, renewables cause significantly lower greenhouse gas emissions than fossil fuels. By deducting the specific emission equivalents per kWh (red bars in Figure 14) from the emissions avoided by not running the mix of conventional plants (blue bars), we obtain the net avoided emissions (grey bars).

> The International Renewable Energy Agency IRENA has developed REmap 2030, a global renewable energy roadmap on how the share of renewables in the global energy mix can be doubled by 2030. Accordingly, Mexico has significant potential for renewable energy. Using this potential could mitigate 102 Mt per year of CO_2 emitted by 2030 (-17% compared to a business-as-usual case). Three quarters of that total mitigation potential comes from the power sector [9].

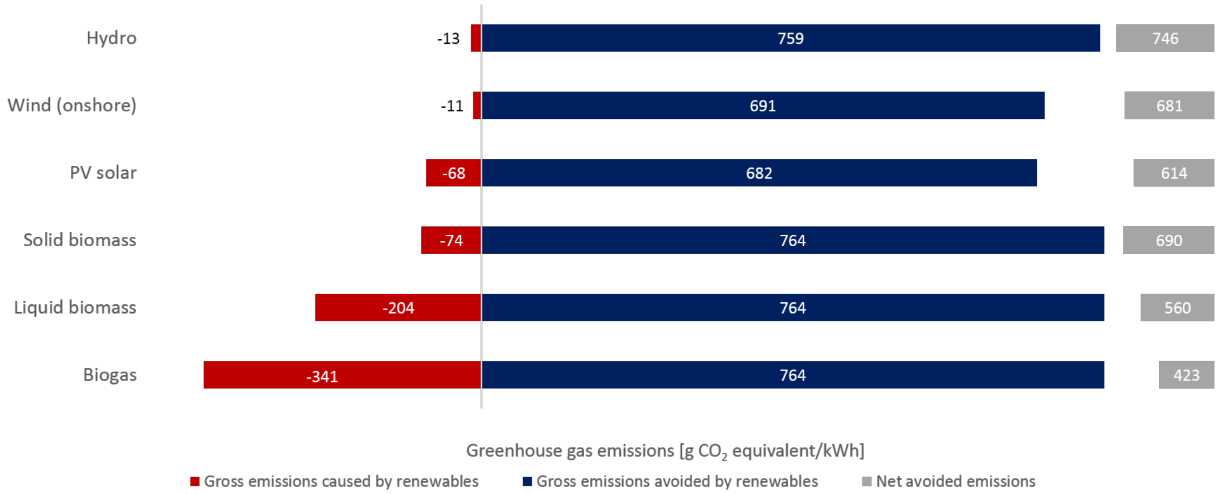

Figure 14: GHG emissions in g CO_2 equivalents per generated kWh electricity in Germany (German Environmental Agency, 2016-1017)

Next, we can calculate the absolute mitigation impacts in tons of CO_2 equivalents for each technology by multiplying the net avoided emission factors with the energy delivered by certain technologies in a given period. The mitigation impact of renewables can then be illustrated across all energy sectors and over time:

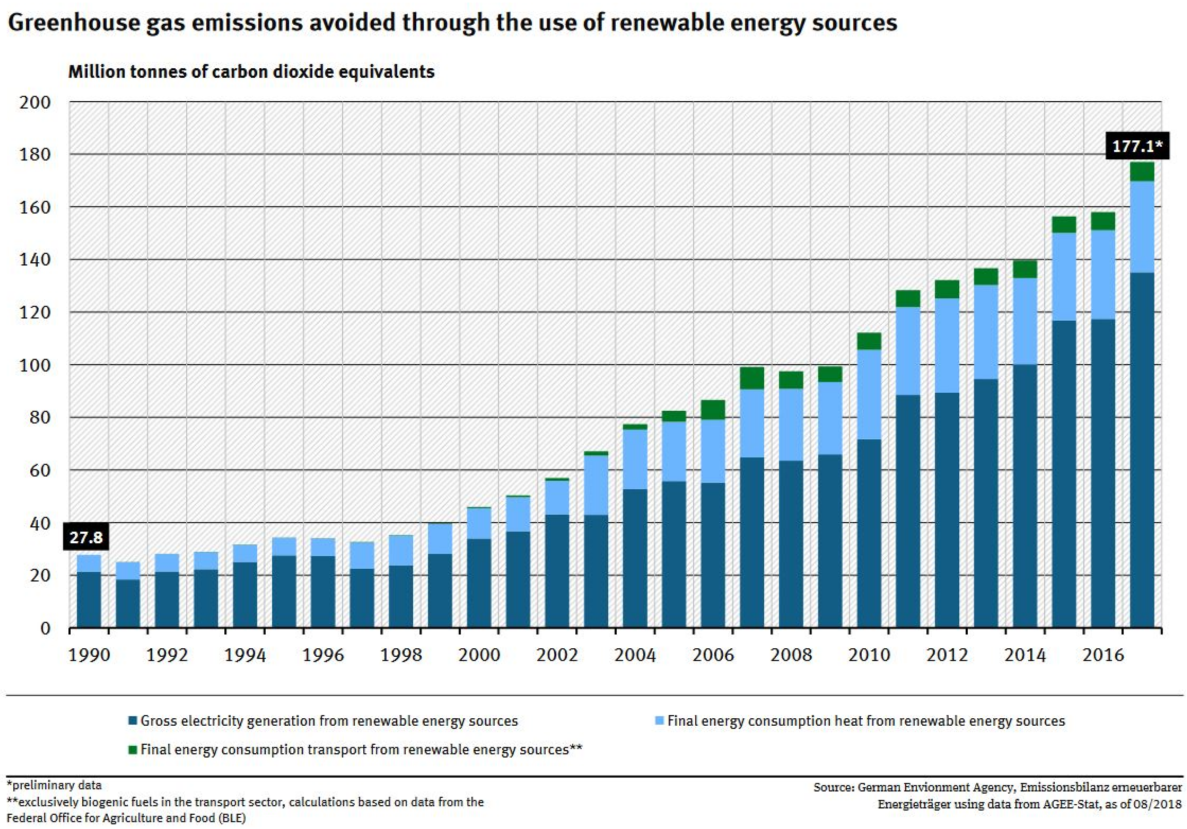

Figure 15: Greenhouse gas mitigation by renewables in Germany (Source: German Environmental Agency, 2018)

In general, renewables also mitigate air pollution. However, the combustion of biomass-based fuels emits particles and acidifiers, especially in traditional stoves [10–11]. Whether bio-energies reduce pollution depends on the technologies they replace.

4.3 Health

Learning objectives: Upon completion of this page, you should be able to

- illustrate how renewable energy promotes health
- identify suitable indicators to quantify health as a co-benefit of renewable energy
- effectively communicate health-related co-benefits of renewable energy

Air pollutants threaten human health in many ways: Acidifiers like nitrogen oxides penetrate lungs and cause or exacerbate asthma and bronchitis. Besides chronic respiratory diseases, particulate matter emissions increase the risk of heart attacks. Even low volumes of toxic heavy metals like mercury (emitted when burning lignite or coal) can have a damaging impact on nervous, digestive and immune systems and inhibit child development [12, 13, 14] [1–3]. These air pollutants can be avoided by using wind and solar energy which also results in lower public health costs [15-16].

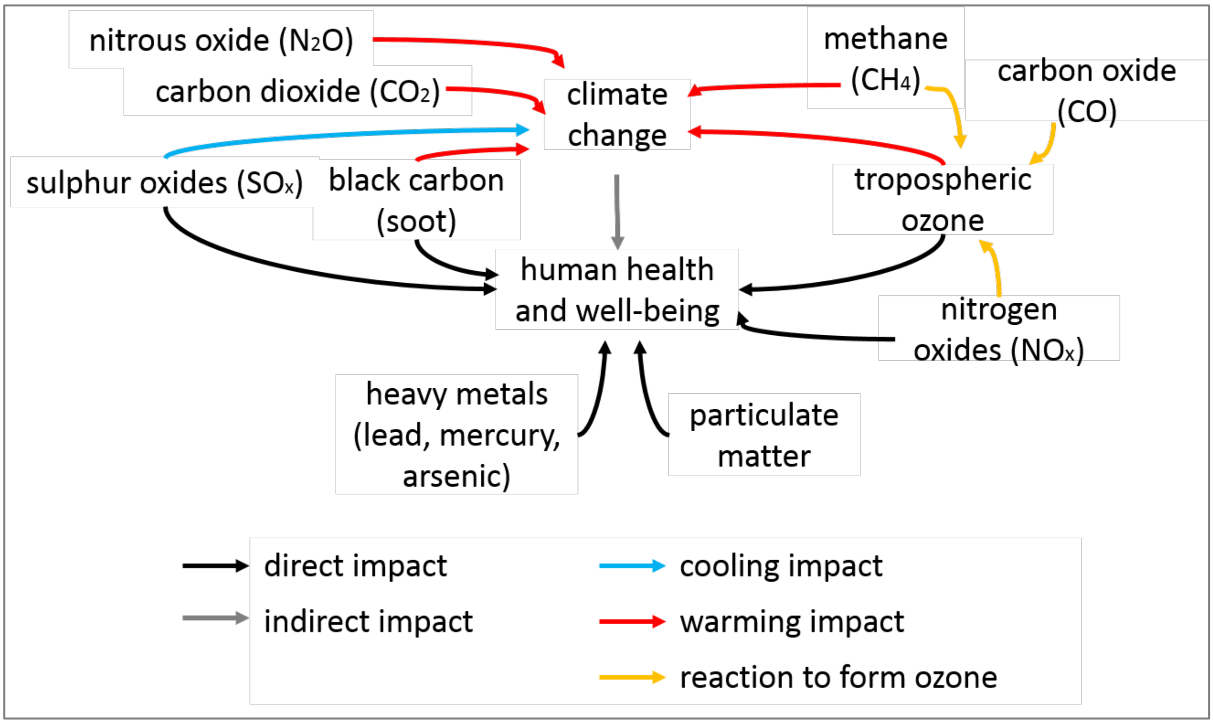

Figure 16: Impacts of and links between substances emitted to the atmosphere (Source: UNEP, 2012)

The World Health Organization (WHO) has set **benchmarks** for the evaluation of health risks related to air pollution (Figure 17). Drawing on these, WHO has developed the indicator "**mortality attributable to joint effects of household and ambient air pollution**" which assesses the average annual exposure of a population to risky concentrations of air pollutants in order to determine the fraction of premature deaths or the years of life lived in less than full health [17]. The co-benefit of renewable energy could thus be derived by monitoring the rate of exposure to air pollutants. It is crucial to consider side effects of available options carefully (e.g. turbine noise of wind parks can be a risk to human wellbeing and noise protection measures should be taken).

Sulfur dioxide
- 20 $\mu g/m^3$ 24-hour mean
- 500 $\mu g/m^3$ 10-minute mean

Nitrogen dioxide
- 40 $\mu g/m^3$ annual mean
- 200 $\mu g/m^3$ 1-hour mean

$PM_{2.5}$
- 10 $\mu g/m^3$ annual mean
- 25 $\mu g/m^3$ 24-hour mean

PM_{10}
- 20 $\mu g/m^3$ annual mean
- 50 $\mu g/m^3$ 24-hour mean

Noise exposure
- below 45 dB 24-hour mean

Figure 17: WHO guidelines: benchmarks for air quality (black) and environmental noise (red) (Source: WHO, 2006 and 2018)

Health costs can be calculated for fossil-based electricity generation – every kWh of electricity generated from coal in South Africa equates to a health cost of Rand 5-15 cents. By scaling up renewable energy, health costs associated to the power sector could be cut by up to 25% by 2050. This would also increase productivity and local economic development [16].

4.4 Energy access

Learning objectives: Upon completion of this page, you should be able to

- illustrate how renewable energy improves energy access as a co-benefit
- identify suitable indicators to quantify energy access as a co-benefit of renewable energy
- effectively communicate benefits of energy access as a consequence of renewable energy

A main co-benefit of renewable energy is that it allows easy and rapid expansion of access to energy, in particular electricity, especially in rural areas, which can have a multiplier effect on development. This is because renewable energy (RE) operates economically at much smaller scales than electricity generated from fossil fuels. Electrification through off-grid RE solutions (e.g. solar home systems (SHS)) or mini-grids can be a cost-efficient solution in areas where the construction of power plants or grid extension would be too expensive or technically unviable. Compared to diesel generators, decentralised RE applications have the advantage that, once installed, they have very low operating costs.

Mexico, which achieved high electrification rates during the first decade of the 21st century, faced significant difficulties electrifying small communities in remote, isolated areas. Mini-grids based on centralised solar farms proved to be the most economic and practical solution [18]. Similarly, Vietnam found that low-wind-speed turbines to electrify clusters in rural areas are the cheapest method for providing electricity access to remote areas [19].

To measure the co-benefit of electricity access, the **share of population or number of households electrified through (off-grid) RE** can be used as an indicator (potentially disaggregated for rural/urban population). It is important first to define electricity access (e.g. access to lighting, electricity and/or cooling) and exclude electrification through energy sources other than renewables for the calculation.

In 2003, when 68% of the Bangladeshi population had no permanent access to electricity, an SHS initiative was implemented. By 2017, 4.12 million systems have been installed in rural households, providing roughly 12% of the population with permanent access to electricity [20].[2]

Other indicators to measure co-benefits include:

- Investments needed to provide electricity access (comparison across technologies)
- Energy expense share in total household budget (affordability)

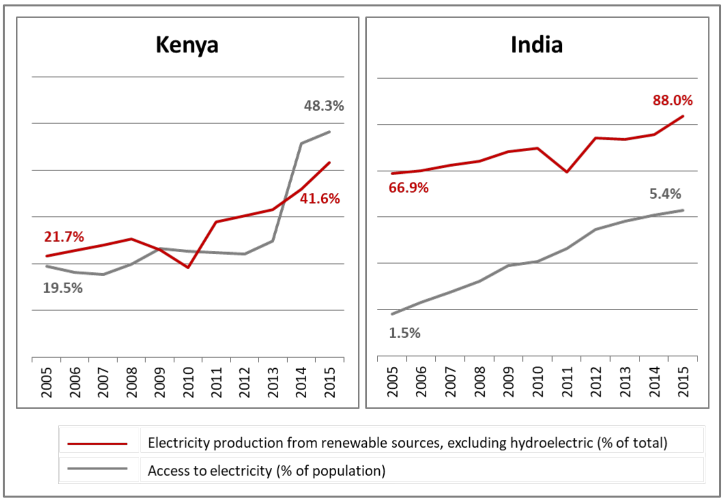

Figure 18: Development of electricity access and electricity produced from RE in Kenya and India (Source: World Bank, 2015)

[2] Just for lighting purposes, this has saved around USD 411 million (for 1.14 million tonnes of kerosene). Considering that an SHS can do more than just provide electricity for lighting, the actual financial savings are a lot higher.

4.5 Local economic development

Learning objectives: Upon completion of this page, you should be able to

- illustrate how renewable energy spurs local economic development as a co-benefit
- identify suitable indicators to quantify local economic development as a co-benefit of renewable energy
- effectively communicate benefits of local economic development as a consequence of renewable energy

The use of renewable energy sources can have a stimulating effect on the local economy by lowering expenditures on electricity, increasing productivity and demand for locally produced goods and services as well as creating employment and providing access to electricity. Impacts on the economic output can be observed during the construction and the operation of a renewable energy plant or project:

- **Direct effects:** Work during project development and construction on site and output generated through the administration, management and operation of the facility.
- **Indirect effects:** Expenditures on inputs, materials, tools and services further upstream the value chain for construction and operation.
- **Induced effects:** Spending and economic activity in the local economy by workers involved in the construction and operation the renewable energy plant or project.

In the long run, renewable energy contributes to creating a more sustainable business environment and higher welfare through lower electricity prices, a cleaner environment and best practice sharing. Furthermore, new business models developed based on RE (e.g. solar kiosks) creates additional opportunities for employment and entrepreneurship.

An input-output analysis helps to evaluate the accumulated economic impact on the local economy measured as **economic output.** The US National Renewable Energy Laboratory (NREL) has developed the Jobs and Economic Development Impact (JEDI) model to calculate economic impacts of the construction and operation of renewable energy projects. The impacts vary depending on the technology used and country-specific industrial patterns.

Figure 19 shows the accumulated economic impacts of the construction and operation of a 50 MW wind park in South Africa over 20 years. According to the input-output analysis, an investment of USD 189 million leads to a gross economic output of USD 439 million. [21]

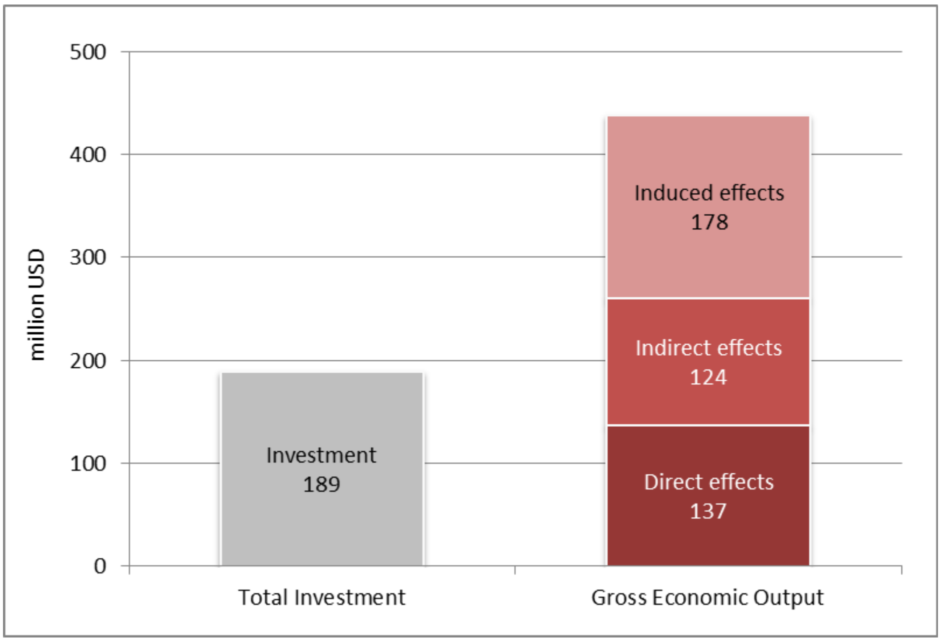

Figure 19: Estimated economic impacts over 20 years of a 50 MW wind farm in South Africa according to the JEDI model (Source: adelphi & FFU, 2019)

Renewable energy development can also create new local industries and alter the trade balance. For example, Turkey has an imbalance between low-tech exports and high-tech imports. By increasing investment in renewable energy, Turkey could increase industrial production by 3.6 million USD in the wind energy sector for each additional MW of capacity. However, without investment in the domestic renewable energy value chains the trade deficit could further increase [22]

4.6 Energy security

Learning objectives: Upon completion of this page, you should be able to

- illustrate how renewable energy promotes energy security as a co-benefit
- identify suitable indicators to quantify energy security as a co-benefit of renewable energy
- effectively communicate benefits of energy security as a consequence of renewable energy

Security of electricity supply is an important driver for socio-economic growth and can be a key co-benefit of renewable energy in different ways:

(a) Reduced blackouts:

Energy supply shortages due to external events and disruptions can lead to repeated blackouts. Diversifying the electricity mix makes a country less vulnerable to such risks.

The **number/duration of blackouts per year** is a possible indicator to measure energy security., in particular security of electricity supply. Renewable energy can reduce blackouts, especially…

- in countries with insufficient energy supply during daytime or low coverage of the power grid, if renewable resources such as wind and solar are available during times of peak load.

- through small-scale off-grid solutions. Local generation relieves the load on the grid and its use can be further optimised through flexibility measures such as flexible thermal generation, strengthening of distribution and transmission grids, demand side management and energy storage or hybrid systems (e.g. PV-diesel).

(b) Independence of fuel imports:

The supply of fossil fuels is dominated by a few nations, making importing countries more vulnerable to unexpected developments in the market. Compared to volatile oil/gas prices, prices for renewable energy resources are rather foreseeable and unaffected by other fuels.

To quantify the benefit of energy independence, **saved expenses for energy imports** can be compared to **costs for new renewable energy plants**. In Kenya, installing renewable energy mini-grids would reduce the annual load on the national grid by 180-570 GWh of coal-based electricity generation, which could save costs for reduced imports of up to USD 17.3 million [23]. However, a country's **willingness to pay for independence** and concerns regarding availability of renewable resources such as wind and solar during times of peak load are not considered in this calculation.

While Morocco's electricity demand rose constantly since 1999, energy imports remained stable at around 90%. More and more electricity demand can be supplied by RE. By 2030, the share of RE in Morocco's electricity mix shall be increased to 52% [24].

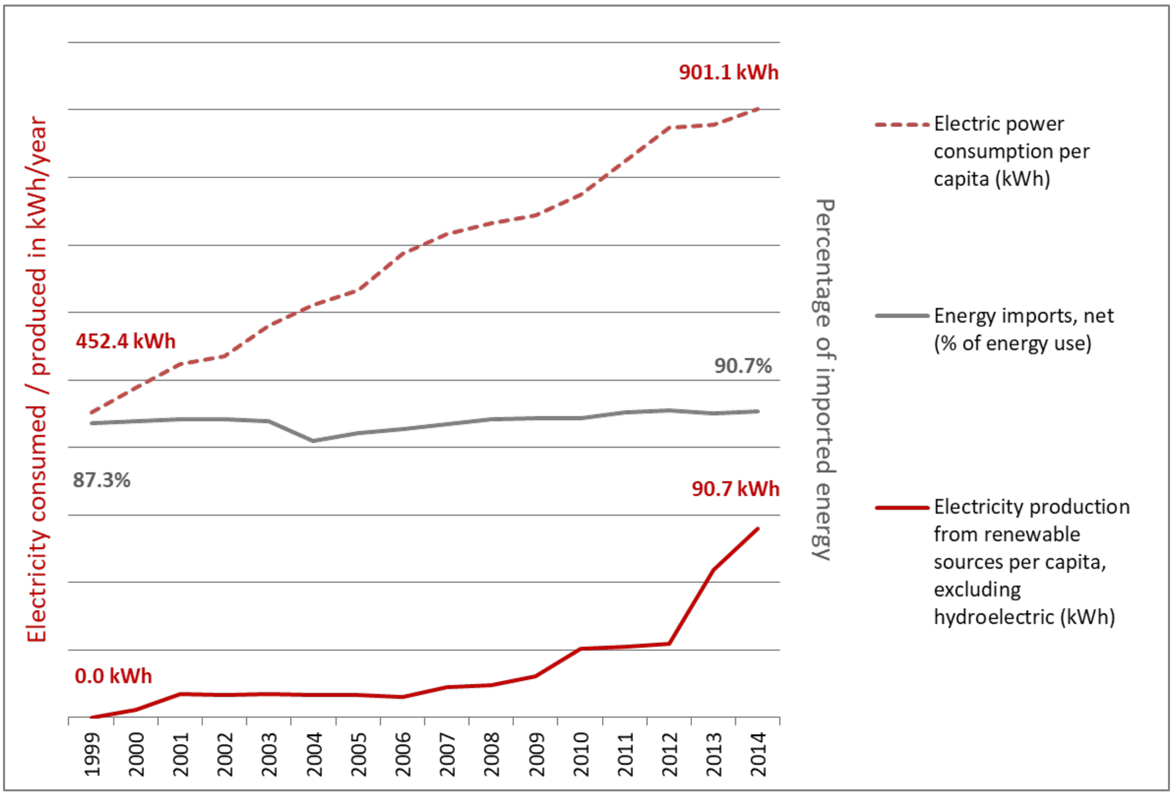

Figure 20: Relationship between electricity consumption, energy imports and renewable energy generation in Morocco from 1999 to 2014 (Source: World Bank, 2014)

4.7 Specialisation of key socio-economic co-benefits in South Africa

Learning objectives: Upon completion of this page, you should be able to

- apply acquired knowledge to the case example South Africa in order to analyse the co-benefit employment in the South African context
- explain the relevance of the co-benefit employment for South Africa

In 2019, 29.1% of the South African population were unemployed [25]. Renewable energy can be seen as a key to **creating new job opportunities.** Due to the local content requirements for RE projects[3] , facilities across the solar PV industry value chain exist in South Africa [26]. For example, ARTSolar, the operator of a 100 MW solar module assembly facility in Durban relies on the aluminium provider Hulamin in Pietermaritzburg. Hence, local content requirements affect not only the assembly factory, but also its suppliers. As a result of the local content requirements, by 2014, more than 20,000 jobs had been created in the South African solar industry [27].

Table 7 shows the potential job creation in South Africa in line with the envisaged solar PV capacity additions according to the Internal Resource Plan (IRP), updated in 2018 [28]:

[3] In each round of the state-run Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), local content requirements were defined for bidding firms.

- 1,474 MW already installed in 2018
- 814 MW between 2019 and 2021 (already contracted)
- 5,670 MW to install between 2022 and 2030 (additional capacity)

The following employment factors are used for the calculation of job creation potential (based on full-time equivalent per Megawatt (FTE/MW)) [29]:

- Manufacturing of solar modules: 16.8 FTE/MW
- Installation and construction of solar PV plants: 7 FTE/MW
- Operation and maintenance (O&M): 0.7 FTE/MW

Number of jobs to be created by solar PV industry		Until 2018	2019-2021	2022-2030	**Total**
Industry	Manufacturing	24,763	13,675	95,256	133,694
	Construction	10318	5,698	39,690	55,706
	O&M	1,032	570	3,969	5,571
	Total	36,113	19,943	138,915	**194,971**

Table 6: Estimation of jobs created through solar PV in South Africa if IRP capacity goals are reached (Source: adelphi, 2019 based on Department of Energy, 2018 and Maia, J. and Giordano, T., 2011)

It can be concluded that increasing RE production in South Africa could have a significant impact on employment, particularly in the long run. If capacity additions are reached, roughly 158,860 jobs could be created between 2019 and 2030. Until 2050, up to 1.6 million additional jobs could be created economy-wide through the power sector transformation [30].

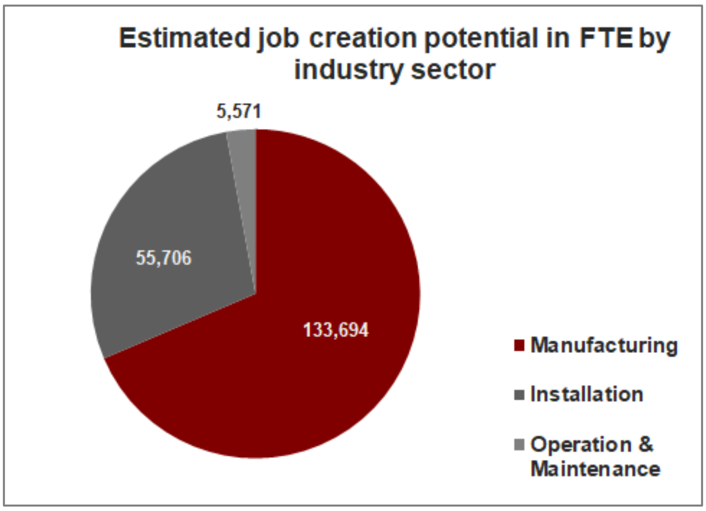

Figure 21: Estimated job creation potential in full time equivalents by sector over a 15-year time horizon (Source: Department of Energy of South Africa, 2018 and Maia, J. and Giordano, T., 2011)

Other significant co-benefits of reaching the goals for RE capacity additions in South Africa include:

- Economic development of marginalised communities
- Improved health through less carbon-intensive electricity production

4.8 Specialisation of key socio-economic co-benefits India

Learning objectives: Upon completion of this page, you should be able to

- apply acquired knowledge to the case example India in order to analyse the co-benefit energy access in the Indian context
- explain the relevance of the co-benefit energy access for India

In 2017, 99.2% of the Indian urban population had **access to electricity** compared to only 89.3% of the rural population [31]. Nationwide, in 2016, 239 million people did not have access to electricity [32]. A similar discrepancy in electricity access can be observed between wealthier and poorer parts of Indian society.

Less than 10 million people of the rural population are estimated to be on track for reliable grid access (e.g. through grid extension plans), whereas the rest are either not connected at all or are grid-connected albeit with unreliable service. [33] Decentralised renewable electricity production from a combination of solar PV, small-scale hydropower and wind turbines could therefore contribute to a maximum coverage of electricity needs [34]. Solar-powered mini-grids can be economically viable and achieve grid parity in rural areas of India [35].

Figure 22 shows the sharp increase of electricity access in rural areas from 29.7% in 1990 to 73.6% in 2014 alongside a significant ramp up of electricity production from renewable sources from 0.2 to 51.7 kWh per capita. [36] This correlation and the underlying rationale suggest that more decentralised RE production can help to supply the remaining quarter of the rural population in India with access to electricity.

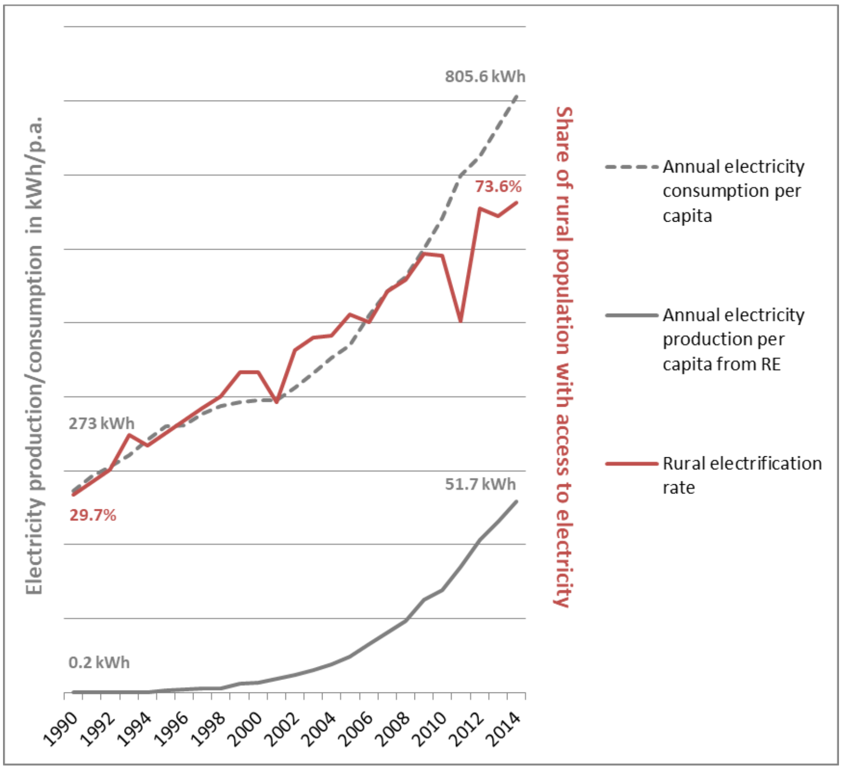

Figure 22: Per capita electricity consumption, electricity production based on RE (excluding hydroelectric), and access to electricity in rural areas from 1990 to 2014 in India (Source: World Bank, 2014)

The Indian government has recognised the importance of RE for solving some of the country's most urgent problems.

This was emphasised for example by the establishment of the Ministry of New and Renewable Energy in 1992 and subsequent policies including the 'Off-grid and Decentralised Solar PV Application Programme'.

The following RE co-benefits are also important in India:

- Improvement of air quality, which helps to counteract associated health risks
- Employment creation, especially in manufacturing and construction

4.9 Specialisation of key socio-economic co-benefits in Vietnam

Learning objectives: Upon completion of this page, you should be able to

- apply acquired knowledge to the case example Vietnam in order to analyse the co-benefit security of electricity supply in the Vietnamese context
- explain the relevance of the co-benefit security of electricity supply for Vietnam

Vietnam has seen a rapid growth of its electricity consumption. Between 2001 and 2015, the primary energy demand has increased by 9.5% annually on average. Until 2011, the country had sufficient natural resources to cover its electricity needs and was even a net oil exporter. However, due to its increased electricity demand, Vietnam has become a net importer of energy and fossil fuels (mainly coal). [39] Considering the continuously growing energy demand, imported energy is expected to make up 37.5% in 2025 and 58.5% of total energy use in 2035. [40]

The fluctuation and often rising oil price combined with Vietnam's increasing reliance on imported fuels has led to frequent electricity shortages. Furthermore, a major part of Vietnam's own electricity production is based on one single source (hydropower), which has been negatively impacted by unfavourable weather conditions in the recent past. [41]

Wind and solar power can contribute to ensure **security of electricity supply**. The resulting diversification of the electricity mix would help to protect the electricity system against blackouts and the independence from fossil fuels would make Vietnam less vulnerable to increases in fuel prices. Wind energy is the most promising form of electricity production for Vietnam with an estimate by the World Bank suggesting that 8.6% of the land area is suitable for the installation of wind turbines. [42] In line with this, the Vietnamese government has set the objective to increase the share of generated electricity from renewable sources to 14% by 2030 compared to 0.1% in 2015. [43 – 44]

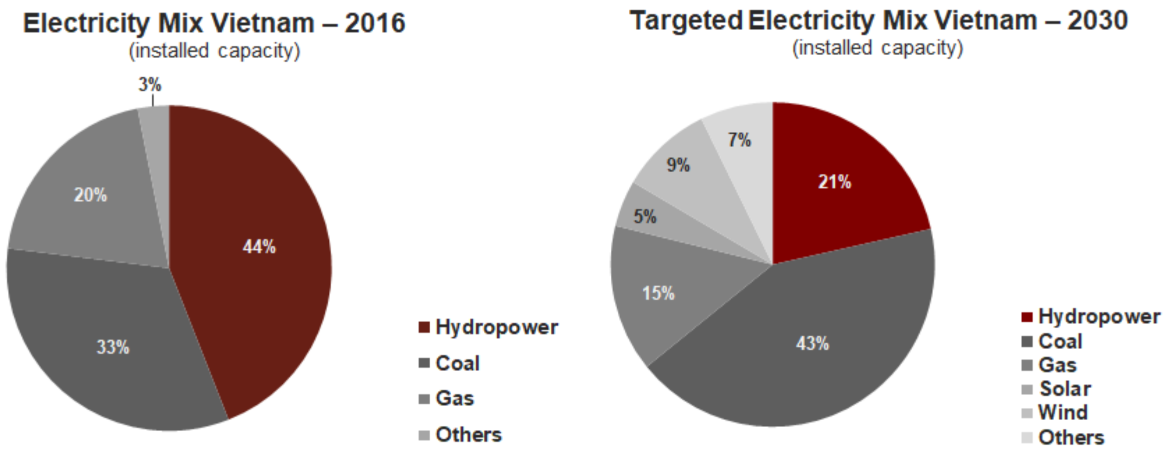

Figure 23: Projected development of electricity mix in Vietnam from 2016-2030 (Source: adelphi, 2019 based on GTAI, 2017)

Further significant co-benefits of reaching the goals for RE capacity additions in Vietnam include:

- Increased electricity access for rural communities
- Job creation, especially in construction and installation

4.10 Specialisation of key socio-economic co-benefits in Turkey

Learning objectives: Upon completion of this page, you should be able to

- apply acquired knowledge to the case example Turkey in order to analyse the co-benefits air quality and health in the Turkish context
- explain the relevance of the co-benefits air quality and health for Turkey

In 2018, 30% of Turkey's primary energy supply came from hard coal and lignite. Turkey aims to increase coal-fired installed capacity from 20 GW in 2019 to 30 GW by 2023 [45]. The combustion of hard coal and lignite is associated with the emission and formation of particulate matter among other air pollutants such as heavy metals.

The recommendations for concentration of particulate matter by the World Health Organization (WHO) as well as the limits by the European Union (EU) are exceeded largely by Turkey.

Particulate matters	WHO recommendation	EU limit	**Turkey**	**Difference to EU limits**
PM2.5	10 µg/m³	25 µg/m³	**37 µg/m³** (2012)	**+ 48%**
PM10	20 µg/m³	40 µg/m³	**54 µg/m³** (2020)	**+ 35%**

Table 7: Particulate matter (PM) concentration in Turkey in 2012 in comparison to WHO recommendations and EU limits (Source: WHO, 2016 and COBENEFITS, 2020)

Estimates by the European Environmental Agency (EEA) conclude that 97.2% of the urban Turkish population are exposed to unhealthy amounts of particulate matter. [46] According to an assessment by the Health and Environment Alliance (HEAL), annual health costs caused by diseases related to coal combustion in Turkey are estimated to be between USD 3.3 and 4.1 billion. Figure 24 shows the immediate causes, which lead to this estimation.

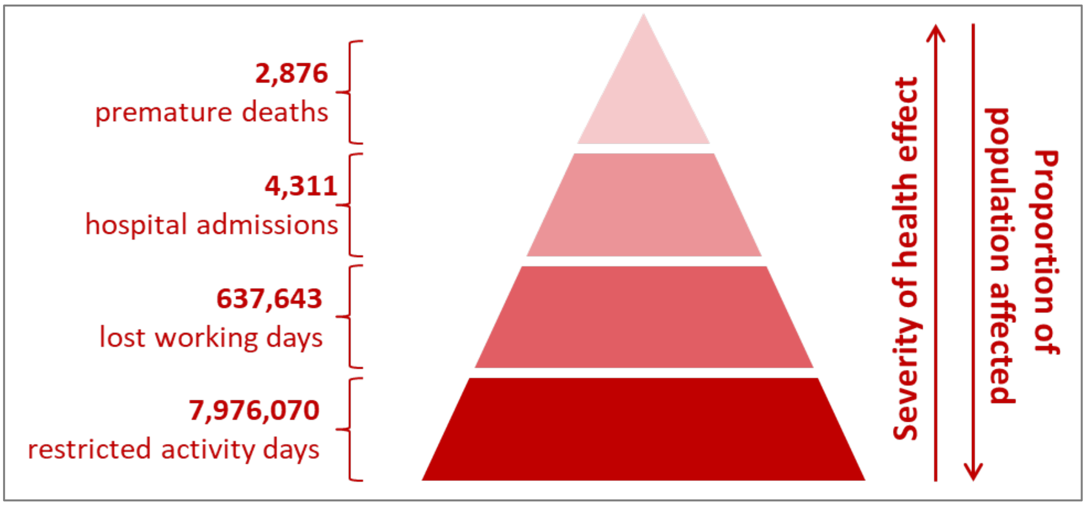

Figure 24: Estimated annual health impact of coal-combusting power plants in Turkey (Source: adelphi, 2019 based on HEAL, 2015)

In 2018, renewable energy (including large hydropower) made up almost a third of the power mix. On the contrary, fossil fuels made up 68% of gross power generation [45]. Turkey has a strong potential for renewable energy. If Turkey installed 30 GW capacity for both wind and solar, health costs savings could amount to USD 764 million in 2028 [47].

4.11 Specialisation of key socio-economic co-benefits in Kenya

Learning objectives: Upon completion of this page, you should be able to

- apply acquired knowledge to the case example Kenya in order to analyse the co-benefit energy access in the Kenyan context
- explain the relevance of the co-benefit energy access for Kenya

In 2017, only 64% of the Kenyan population had **access to electricity**. Electricity access advanced faster in urban than rural areas. Approximately two thirds of the Kenyan population live in proximity to one another. In those urbanised areas over 80% of the population had access to electricity. The remaining third of the Kenyan population spreads across the country in sparsely populated areas, which are often best served by renewable energy solutions [48]. In 2017, almost half of the population in rural areas had no access to electricity [49].

In 2013, the Government of Kenya set a target of 100% access to electricity by 2022. The electrification rate in Kenya has increased tremendously over the past few years; however, there was still a significant gap of 36% (in 2017) to close ahead of 2022. While around 2.8 million households can gain access to electricity by connecting to the grid (see Figure 25), this option is too expensive in rural and remote areas. Thus, renewable energy is key to realise the target. To drive forward electrification, the 2019 Energy Act established the Rural Electrification and Renewable Energy Corporation with the mandate to foster renewable energy and implement rural electrification projects [50].

To achieve the electrification, target local mini-grid solutions can be developed, solar home systems installed or the existing grid extended. In 2015, the Government of Kenya drafted the Kenya National Electrification Strategy (KNES). Standalone solar home systems can provide access to electricity for 1.96 million households, many of whom are in rural and remote areas. By building an additional 121 mini-grids consisting of a solar photovoltaic array, battery storage and an inverter another 35,000 households can be connected [51]. To achieve full electrification also in remote areas, renewable energy solutions are crucial (see Figure 25).

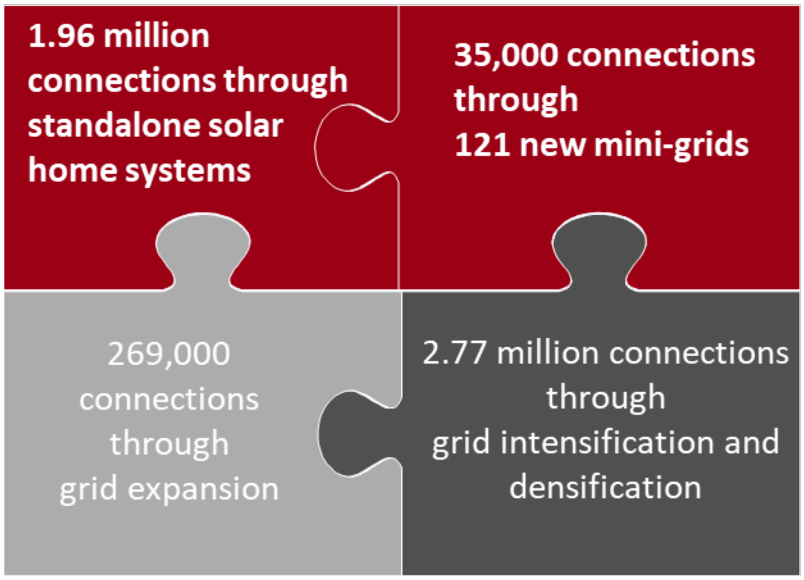

Figure 25: Measures to achieve full electrification according to Kenya National Electrification Strategy (Source: adelphi, 2020 based on Ministry of Energy, 2018)

4.12 Specialisation of key socio-economic co-benefits in Mexico

Learning objectives: Upon completion of this page, you should be able to

- apply acquired knowledge to the case example Mexico in order to analyse the co-benefit energy security in the Mexican context
- explain the relevance of the co-benefit energy security for Mexico

Mexico's electricity mix is dominated by fossil fuels. In 2016, almost 80% of generation was fossil, while just 20% were produced from clean energy sources [52]. The primary electricity source is natural gas. Mexico's long-standing position as one of the world's largest oil producers has weakened in recent years [53]. Natural gas output has also been in decline, as most gas production is associated with oil. With the 2014 Electricity Law, the electricity market was liberalised, allowing for competition on the natural gas market. Between 2005 and 2015, the gross domestic product grew 2.7% annual average, as a result, the consumption of electricity grew at a 3% rate [54]. Even with increased domestic production due to the reforms, natural gas imports are projected to rise by 53% by 2030. This growth is driven by the continuing increase in demand. In 2015, Mexico imported more than 70% of its primary electricity resource natural gas; more than 90% of those imports come from the US. Dependence on imports, and even more so dependence on a single trade partner, is a major concern for **security of electricity supply**.

Between 2015 and 2030 natural gas imports from the US are projected to grow on average by 2.8% annually [55]. Mexico's Electricity Sector Outlook expects an annual growth in electricity demand of 3.4% until 2030. In order to meet the growing electricity demand almost 60 GW of additional capacity would be needed. At the same time, Mexico has significant potential for various renewable energy technologies, most importantly wind energy. Renewable energy has become increasingly cost-competitive over the last years and can achieve very high capacity factors in Mexico. Leveraging and deploying renewable energy to meet electricity demand is a key aspect in the 2014 Electricity Law. With the law, Mexico started a broad energy reform to liberalise its energy market, diversify its electricity mix and achieve 40% in power generation from zero or low emission energy types by 2035, and 50% by 2050.

By 2030, 62% of projected capacity additions could be clean energy technologies (wind power, CHP plants, solar PV, hydro, nuclear and geothermal) (see Figure 26). Wind energy alone could add 12 GW to the electricity system by 2030. Up to 50 GW of wind energy are theoretically possible [56]. Mexico's geographical position means that it is also optimally located for solar energy. Leveraging available domestic electricity generation capacity with a focus on renewable energy will be key to sustaining economic growth, reaching renewable energy and climate targets and becoming increasingly independent of energy imports.

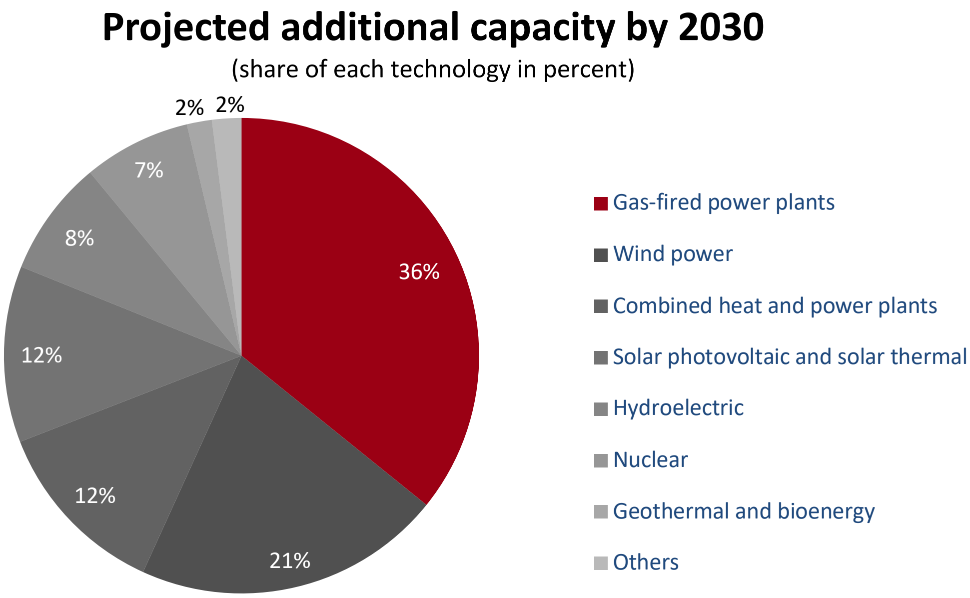

Figure 26: Projected capacity additions in Mexico by 2030 (Source: adelphi, 2020 based on SENER, 2016)

A rapid expansion of renewable energy could also benefit the following co-benefits in Mexico:

- Climate and environment
- Employment creation and future skills

4.13 Chapter endnotes

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4.14 Further readings

Further readings for screen page 4.1:

The "Guidelines for employment impact assessment or renewable energy development" provide a more comprehensive step by step description to assess indirect and induced employment impacts with I-O-tables and employment factors:

- https://ecomod.net/system/files/Paper_Ecomod_2012_Nathani.pdf

The article "Renewable technologies in Karnataka, India: jobs potential and co-benefits" can serve as an example of how to adapt general employment factors for different energy sectors to a national context. The study also contains employment factors for the biofuel sector:

- https://doi.org/10.1080/17565529.2017.1410085

The instructive and recent study "Greening India's workforce" by NRDC and CEEW establishes employment factors and job impacts of solar and wind power for India:

- https://www.nrdc.org/sites/default/files/greening-india-workforce.pdf

Besides assessing the quantitative impacts on job creation, the executive briefing "The future development of employment in South Africa's power sector with growing share of renewable energy" by CSIR and ERC UCT looks into the aspects of timing and the labour market:

- https://www.cobenefits.info/wp-content/uploads/2018/10/COBENEFITS-South-Africa_Employment_draft-final-results.pdf

This paper provides an overview of different impact assessment studies that analyse employment impacts or renewable energy and clarifies which methodological approach is best suited:

Breitschopf, B.; Nathani, C. and Resch, G., *Review of approaches for employment impact assessment of renewable energy deployment*, 2011.

Further readings for screen page 4.2:

To read more about the mitigation potentials of renewable energy technologies, please consult the IPCC report "Renewable energy sources and climate change mitigation":

- https://www.ipcc.ch/pdf/special-reports/srren/SRREN_FD_SPM_final.pdf

With a view to the partner country Kenya, this report explains why renewable energy resources are key to achieving climate change mitigation targets:

- Dalla Longa, F., van der Zwaan, B. 'Do Kenya's climate change mitigation ambitions necessitate large-scale renewable energy deployment and dedicated low-carbon energy policy?', *Renewable Energy*, Volume 113, p. 1559-1568, 2017.

This study on Turkey explains why renewable energy is one of the most efficient solutions for sustainable energy development in Turkey in line with global environmental policy targets:

- Keleş, S., Bilgen, S. 'Renewable energy sources in Turkey for climate change mitigation and energy sustainability', Renewable and Sustainable Energy Reviews, Volume 16, Issue 7, p. 5199-5206, 2012.

Further readings for screen page 4.3:

Another way to illustrate the adverse impacts of air pollution is this short film by the WHO:

- https://www.youtube.com/watch?v=GVBeY1jSG9Y&feature=youtu.be

More information on the methodology to assess health risks attributable to air pollution can be found here:

- http://www.who.int/healthinfo/global_burden_disease/about/en/

To learn more about specific projects in which renewables have ameliorated energy access of hospitals you can consult the conference homepage "Renewable energy solutions for health care facilities":

http://iorec.irena.org/Home/Healthcare

Further readings for screen page 4.4:

For more information on the case of Kenya, have a look at UNDP's report about the NAMA programme in Kenya and how they implemented measures to ensure energy access through solar plants:

- United Nations Development Programme (UNDP), *Nationally Appropriate Mitigation on Access to Clean Energy in rural Kenya through innovative Market Solutions,* 2016, accessible at: http://www.undp.org/content/undp/en/home/librarypage/environment-energy/mdg-carbon/NAMAs/nama-on-access-to-clean-energy-in-rural-kenya-through-innovative.html.

For detailed insights into the market trends and impacts of off-grid solar systems see:

- Lightning Global, *Off-Grid Solar Market Trends Report 2018,* 2018, accessible at: https://www.lightingafrica.org/wp-content/uploads/2018/02/2018_Off_Grid_Solar_Market_Trends_Report_Full.pdf.

For a thorough analysis of the relationship between energy access and sustainable development, take a look at IEA's Energy Access Outlook 2017:

- International Energy Agency (IEA) / OECD, *Energy Access Outlook 2017 – From Poverty to Prosperity,* 2017, accessible at: https://www.iea.org/access2017/.

Further readings for screen page 4.5:

For a more theoretical approach to economic impact of RE have a look at the following article:

- Delrio, P. and Burguillo, M., 'Assessing the impact of renewable energy deployment on local sustainability: Towards a theoretical framework', *Renewable and Sustainable Energy Reviews*, 12, 2008.

The study "Economic prosperity for marginalised communities through renewable energy in South Africa" takes a different angle and assesses how revenue spending towards socio-economic development and enterprise development can help create prosperity in marginalised communities in South Africa:

- Okunlola, A. et al., *Economic prosperity for marginalised communities through renewable energy in South Africa*, 2019.

Further readings for screen page 4.6:

For different (more complex) attempts to quantify the contribution of renewable energy to energy security have a look into the following publications:

- Valdés Lucas, J. N.; Escribano Francés G. and San Martín González, E., 'Energy security and renewable energy deployment in the EU: Liaisons Dangereuses or Virtuous Circle?', *Renewable and Sustainable Energy Reviews*, 62, 2016, pp. 1032-1046, accessible at: https://www.sciencedirect.com/science/article/pii/S1364032116301022#!.
- Vaona, A., 'The effect of renewable energy generation on import demand', *Renewable Energy*, 86 (2016), 354-359, accessible at: https://pdfs.semanticscholar.org/f4ad/562cd6f14ced015e4dfb685f0a79258049b6.pdf.

For more detailed information on reliable capacities refer to RENAC's training course GESS IIIb: Introduction to Grid Integration of Variable Renewable Energy:

- https://www.renac.de/trainings-services/trainings/open-trainings/produkt/gess-iiib-introduction-to-grid-integration-of-variable-renewable-energy/

Further readings for screen page 4.7:

For a more detailed evaluation of the employment creation potential of different renewable energy sources in South Africa have a look at:

- Maia, J., Giordano, T., *Green Jobs. An Estimate of the Direct Employment Potential of a Greening South African Economy*, 2011.

This study assesses the impacts of coal phase-out plan, including those on jobs:

- Burton, J.; Caetano, T. and McCall, B., *Coal transitions in South Africa - Understanding the implications of a 2°C-compatible coal phase-out plan for South Africa*, Energy Research Center, University of Cape Town, 2018, accessible at: https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Rapport/20180609_ReportCoal_SouthAfrica.pdf

This study examines how more ambitious renewable energy targets can lead to more local jobs:

- Okunlola, A. et al., *Economic prosperity for marginalised communities through renewable energy in South Africa*, 2019.

Further readings for screen page 4.8:

To learn more about how hybrid RE systems can cover electricity needs have a look at the case study about the off-grid remote village Palari in the state of Chhattisgarh, India:

- Sen, R. and Bhattacharyya, S. C., 'Off-grid electricity generation with renewable energy technologies in India: An application of HOMER', *Renewable* Energy, Vol. 62, 2014, pp. 388-398, accessible at: https://www.sciencedirect.com/science/article/pii/S0960148113003832.

More information on how renewable energy contributes to air quality and resulting health benefits can be found here:

- Boudri, J et al., 'The potential contribution of renewable energy in air pollution abatement in China and India', *Energy Policy,* vol. *30, no.* 5, 2002, pp. 409-424., accessible at: https://www.sciencedirect.com/science/article/pii/S0301421501001070.

To get a clearer understanding of how renewable energy creates job opportunities in rural India have a look at:

- Ghosh, A. et al., *Clean energy powers local job growth in India*, NRDC, 2015, accessible at: https://www.nrdc.org/sites/default/files/india-renewable-energy-jobs-IR.pdf.

Further readings for screen page 4.9:
Selvakkumaran's article offers a very detailed evaluation of impacts of renewable energy on energy security

- Selvakkumaran, S. and Limmeechokchai, B., 'Energy security and co-benefits of energy efficiency improvement in three Asian countries', *Renewable and Sustainable Energy Reviews,* 20, 2013, pp. 491–503, accessible at: https://www.sciencedirect.com/science/article/pii/S1364032112007009.

The Danish Energy Agency provides a detailed overview of the energy situation and outlook in Vietnam:

- Danish Energy Agency, *Vietnam Energy Outlook Report 2017*, accessible at: https://ens.dk/sites/ens.dk/files/Globalcooperation/Official_docs/Vietnam/vietnam-energy-outlook-report-2017-eng.pdf.

More information on how off-grid renewable energy systems are more cost-competitive than grid extension for increasing electricity access for rural communities can be found here:

- Okunlola, A. et al., *Electricity access and local value creation for the un-electrified population in Vietnam*, 2019.

To get a clearer picture of the employment opportunities renewable energy can create, look at this report:

Okunlola, A. et al., *Future skills and job creation through renewable energy in Vietnam*, 2019.

Further readings for screen page 4.10:
IEA provides country reports on energy policies, including information on the topic of air pollution. For Turkey, the country report can be downloaded here:

- https://webstore.iea.org/energy-policies-of-iea-countries-turkey-2016-review

The World Health Organization (WHO) collects information on air pollution worldwide. The concentration of fine particulate matter per country in 2016 can be accessed here:

- http://apps.who.int/gho/data/view.main.SDGPM25116v

Further readings for screen page 4.11:
To learn more about how Kenya addresses the need for electricity stability while respecting GHG emission reduction targets have a look at this study:

- Kahlen, L., Kurdziel, M., Day, T. and Schiefer, T., *The role of geothermal and coal in Kenya's electricity sector and implications for sustainable development*, 2018.

This study examines different electrification strategies for Kenya and highlights the role of renewable energy for achieving electricity access for rural households:

- Moner-Girona, M. et al., 'Dezentralized rural electrification in Kenya: Speeding up universal energy access', *Energy for Sustainable Development*, Volume 52, Issue 10, 2019, pp 128-146

This article focuses on the co-benefits and opportunities of solar electrification and how the main challenges can be addressed by policy reform:

- George, A., Boxiong, S., Arowo, M., Ndolo, P., Chepsaigutt-Chebet and Shimmon, J., 'Review of solar energy development in Kenya: Opportunities and challenges', *Renewable Energy Focus*, Volume 29, p. 123-140, 2019.

To find general information on key energy data for Kenya, have a look at the Kenya Energy Outlook by the International Energy Agency:

- International Energy Agency, *Kenya Energy Outlook*, 2019, retrieved from: https://www.iea.org/articles/kenya-energy-outlook

Further readings for screen page 4.12:
To find general information on key energy data for Mexico, have a look at the report by the International Energy Agency:

- International Energy Agency, *Energy policies beyond IEA countries: Mexico 2017*, 2017, retrieved from: https://www.iea.org/reports/energy-policies-beyond-iea-countries-mexico-2017

More information on the mentioned and other co-benefits of renewable energy in Mexico can be found in this report:

- GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), *Co-beneficios: Contribución de la Transición Energética para el Desarrollo Sostenible en México*, 2020

In line with the growth of renewable energy and the step-wise reduction of fossil duels, the following article determine the optimal mix of renewable energy and fossil fuels in the medium term until 2024:

- Vidal-Amaro, J.J., Østergaardb, P.A. and Sheinbaum-Pardoa, C. 'Optimal energy mix for transitioning from fossil fuels to renewable energy sources – The case of the Mexican electricity system', *Applied Energy*, Volume 150, p. 80-96, 2015.

5 Summary

5.1 Summary of the course

Learning objective: Upon completion of this page, you should be able to

- recapitulate the contents of the course

This course elaborated on assessment tools and methodologies to measure social and economic co-benefits of promoting renewable energy and to better communicate these results. The starting point (chapter 2) were scoping methods to identify possible effects (see second box in Figure 25). Direct, indirect, and induced effects as well as gross and net effects can be differentiated. In this context, we introduced dimensions like timing (short, medium and long-term impacts) and scale (local versus national) to the observed impacts.

The third chapter of the course presented modelling tools for in-depth analyses. These focused on macroeconomic tools (I-O-tables, CGE-modelling) that help to analyse economy-wide aspects or impacts between industries. Moreover, the course dealt with distributional impacts within parts of the population or within economic sectors. In addition, multi-criteria and cost-benefit analyses were suggested as methods to compare the advantages of different policy options.

Chapter 4 presented impact areas in which scoping techniques and modelling tools can be applied, namely, employment, climate, environmental, and health impacts as well as impacts on local economic development, energy access, and energy security. In this context, the course elaborated on indicators which were introduced in previous courses, such as units for employment impacts (e.g. full-time equivalent). Finally, the course applied the methodologies and knowledge to some of these co-benefits in selected countries.

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