Decision-support tools for climate change mitigation planning

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Decision-support tools for climate change mitigation planning

A non-technical guide written by Daniel Puig and Sandra Aparcana (UNEP DTU Partnership)

About this document

This document describes three decision-support tools that can aid the process of planning climate change mitigation actions. The phrase 'decision-support tools' refers to science-based analytical procedures that facilitate the evaluation of planning options (individually or compared to alternative options) against a particular evaluation criterion or set of criteria. Most often decision-support tools are applied with the help of purpose-designed software packages and drawing on specialised databases.

The evaluation criteria alluded to above define and characterise each decision-support tool. For example, in the case of life-cycle analysis, the evaluation criterion entails that the impacts of interest are examined across the entire life-cycle of the product under study, from extraction of raw materials, to product disposal. Effectively, then, the choice of decision-support tool directs the analysis towards a specific type of decision criterion.

The appeal of decision-support tools lies in the process associated with their application. This process entails a rigorous identification and review of all aspects relevant to the evaluation being conducted. The transparency of the process can be greatly enhanced when these steps are documented. Doing so increases the credibility of the evaluation, which gives its results increased legitimacy among relevant stakeholders.

This document complements one other related guide, focused on valuation of climate change mitigation co-benefits. Both guides aim at presenting in non-technical language a set of analytical tools that can support the planning of climate change mitigation actions by national and sub-national government agencies. To the extent that developing country government agencies have comparatively less human and technical capacities than their developed country counterparts, these guides are primarily directed at supporting developing country government agencies.

Contents

Structure of the document

The remainder of this document is structured around three main elements, as follows:

Decision-support tools aid the decision-making process. They do so by providing a well-established – and, therefore, predictable – analytical framework, the application of which entails a thorough and rigorous review of all relevant aspects surrounding the decision concerned. As such, decision-support tools do not provide a 'decision' per se, but rather critical input to the process through which that decision will be made.

TYPES OF DECISION-SUPPORT TOOLS

Several decision-support tools are available. In this document we describe three widely-used decision-support tools: life-cycle analysis, cost-benefit analysis, and multi-criteria decision analysis. Table 1 illustrates some of the key features of these decision support tools.

Table 1: Key features of selected decision-support tools

Tool	Decision criterion	Advantages	Challenges	Application
Life-cycle analysis	Explore impacts 'from cradle to grave'	Comprehensive overview Intuitive analytical method	Data-intensive method Under-developed quality-control	Interventions where the environmental (and social) impacts of comparable products, processes or services may vary along the life-cycle of those products, processes or services
Cost-benefit analysis	Maximise the monetary value of social welfare	Perceived credibility Understandable metric	Monetisation and aggregation Ignored uncertainty	Well-specified interventions with tangible price-centred benefits and costs
Multi-criteria decision analysis	Balance multiple objectives	Stakeholder engagement Integration of different metrics	Eliciting subjective judgements Multiple solutions may hamper consensus	Multiple and systemic interventions reflecting plural values and relying on a participatory-based approach

Life-cycle analysis

In addition to allowing comparison among different products, processes or services, life-cycle analysis provides the information required to modify those products, processes or services, so as to reduce their impacts on human health and the environment. For the product, process or service of interest, and from a cradle-to-grave perspective, a typical life-cycle analysis will involve the following steps: determining energy and material inputs, and polluting emissions; evaluating the environmental (and/or social) impact associated with those inputs and emissions; and interpreting the results of the evaluation with regard to their environmental and human health consequences.

Cost-benefit analysis

The rationale behind cost-benefit analysis is that a certain course of action should only be pursued if its net present value is positive. To this end, cost-benefit analysis estimates in monetary terms both the costs and benefits of that course of action. Often, this requires that assumptions are made about elements in the cost or benefit decision for which there are no markets: for those elements, monetary values have to be derived through purpose-developed valuation techniques. In all cases, cost and benefits that accrue in the future are valued less than those that accrue in the present, a practice that is referred to as 'discounting'.

Multi-criteria decision analysis

Multi-criteria decision analysis refers to a range of formalised methods that are used as input to the decision-making process in situations where uncertainty is high, objectives are different or even conflicting, metrics are heterogeneous, and complex systems are the subject of the analysis. Multi-criteria decision analysis (i) takes account of multiple objectives through the criteria it uses, and the weight each criterion is given; (ii) involves a transparent process that produces easy-to-communicate results; and (iii) provides results in a manner that supports stakeholder engagement, without incurring prohibitive financial costs or requiring unreasonably long time frames.

USAGE IN A CLIMATE CHANGE CONTEXT

Still today cost-benefit analysis is the decision-support tool that enjoys most popularity as aid to decision making within climate change (and environmental management more broadly). This is partly because cost-benefit analysis has been widely used in most public policy decision processes, owing to its strong economic focus. Familiarity with the tool has helped extend its use to decision-making for climate change.

Life-cycle analysis is mainly used to explore the environmental impact of comparable products, processes or services, when these products, processes or services differ with regard to the way they are manufactured, transported, used and disposed of. The use of life-cycle analysis has recently been extended to analyse the social impacts of products, processes and services. In a climate change context, most applications of life-cycle analysis are found in the area of waste management.

Multi-criteria decision analysis is emerging as the tool of choice in decision processes faced with multiple metrics, or diverse and sometimes conflicting priorities. Typical examples of the use of multi-criteria decision analysis in a climate change context include decisions concerning the desirable evolution of the fuel mix in a given country, or decisions about nuclear energy waste disposal sites, to cite but two types of applications.

Decision-support tools are not mutually exclusive. On the contrary, and provided that the resources to do so are available, using different tools to analyse the same problem can be beneficial to the decision-making process. Not least, it is worth noting that multi-criteria decision analysis can rely on other decision-support tools, notably cost-benefit analysis.

Life-cycle analysis

Definition

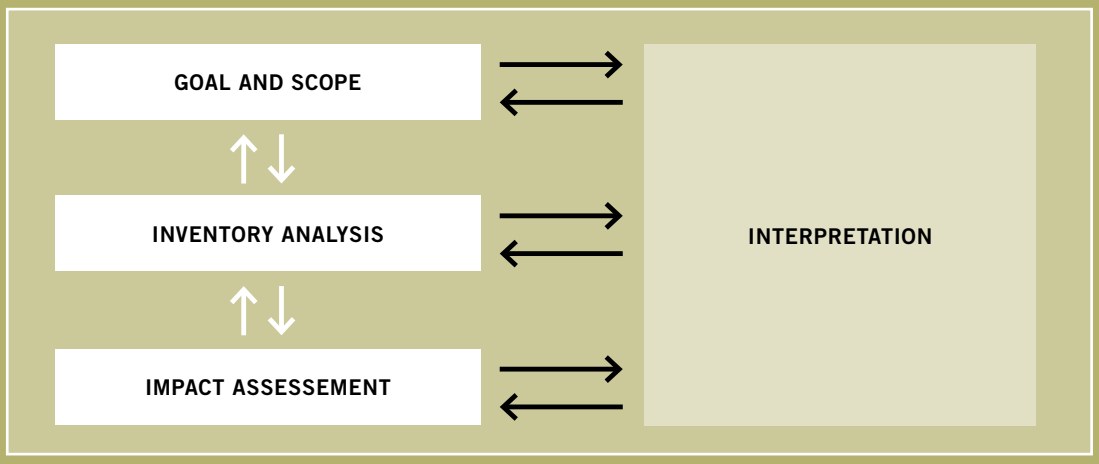
Life-cycle analysis is an analytical technique that is used to determine the environmental, economic and social impacts of a product, from its manufacture to its end-of-life. Life-cycle analysis complements other decision-support tools by providing a measure of environmental performance and risk.

Key steps of a life-cycle analysis

Life-cycle analysis concerns itself with all the stages in the 'life' of a good or a service, from extraction of raw materials up to final disposal (and all possible end-of-life processes implied in this stage). It provides a measure of environmental impacts by quantifying all material and energy inputs (resources, energy, and raw materials), and outputs (emissions to air, land and water, solid waste generation, and waste water) at each of those stages. Figure F1.1 illustrates the main steps of a life-cycle analysis.

Fiche 1

Figure F1.1: Key steps of a life-cycle analysis



Source: based on ISO 14040

Goal and scope definition

In this phase, the goal of the assessment is established, the boundaries of the system are defined, and additional framing conditions are set. The latter includes, for example, the functional unit, which defines the metrics used to quantify the main function of the product or service (for instance, a tonne of solid waste to be disposed of, or one square meter of painted wall). Setting framing conditions

also entails agreeing on the processes to be covered (for instance, extraction of raw materials, manufacturing, and recycling), on the environmental impact categories (such as global warming or eutrophication), on the type of data needed, or the steps to be taken to collect relevant data.

Life cycle inventory analysis

This phase entails the collection of all relevant data. The data collection stage is then followed by a quantification of inputs and outputs related to the functional unit, in all process phases.

Impact assessment

In this phase all expected environmental impacts are calculated, drawing on the data of the life-cycle inventory (the previous phase). The goal of this phase is to understand and evaluate the magnitude and significance of the potential environmental impacts of the product or service under study. Simply stated, the impact assessment phase helps identify impact pathways, thus connecting outputs and emissions to their environmental impacts.

Interpretation

This phase summarises and discusses the results of the analysis. The outputs of the interpretation phase, more than the analysis itself, are used for decision-making purposes.

Stakeholders involved

Different stakeholders may be needed to conduct a life-cycle analysis, the precise type depending on the system analysed and the data available for the analysis. For instance, if the system boundaries of the analysis include upstream processes (such as raw materials extraction or processing), it may be necessary to involve raw materials providers, to obtain data about their processes, energy consumption, and type of fuel used. Similarly, if the end-of-life phase of a product is included in the analysis, stakeholders in charge of recycling and waste treatment processes are likely to be needed.

Typical applications and limitations

Life-cycle analysis can be applied to choose environmentally sound materials (a product design that pollutes less, along its entire life cycle), or to invest in innovative technologies. Similarly, life-cycle analysis can help decision makers to identify the advantages of different processing methods, based on their environmental impacts. For example, it can be used to determine the most suitable option between recycling (material recovery) or energy recovery through incineration (in the case of waste treatment alternatives). Furthermore, it offers the possibility of assessing upstream and downstream trade-offs regarding environmental impacts, human health and resource consumption. Life-cycle analysis has been used in agriculture, waste management, food processing, eco-design of home appliances, and in the garment industry, among many others sectors.

Conducting a life-cycle assessment is not without challenges. Several barriers may arise, depending on the product, service, or scenario targeted. In some cases, the level of effort and costs associated to setting system boundaries and/or collecting required data makes it prohibitive to conduct a life-cycle assessment.

F1

In those instances, one may want to simplify the process by focusing on key products and services only.

Lastly, any life-cycle assessment requires making assumptions about unknown parameters. The uncertainty associated to these assumptions has to be reflected in the interpretation of the findings of the analysis.

Typical costs and time frames

As noted above, the costs and time invested in conducting a life-cycle analysis are strongly dependent on the goal of the study, the complexity of the system, and the availability and quality of the data, among other factors. However, several tools, such as life-cycle analysis software and databases, have been developed, which help reduce time, costs, and some of the uncertainties related to data quality and methodologies for calculating impacts. A list of life-cycle analysis software tools can be found at the end of Annex 1.

For further reading

Lehtinen, H., Saarentaus, A., Rouhiainen, J., Pitts, M., Azapagic, A. (2011). *A Review of LCA Methods and Tools and their Suitability for SMEs*. Pöyry Management Consulting Oy, Chemistry Innovation Ltd, and The University of Manchester. Vantaa, Finland; Runcorn, United Kingdom; and Manchester, United Kingdom.

ISO (2006). *ISO 14040:2006 Environmental management. Life cycle assessment. Principles and framework*. International Standards Organisation. Geneva, Switzerland.

Baumann, H., Tillman, AM. (2004). *The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Applications*. Studentlitteratur. Lund, Sweden.

Cost-benefit analysis

Definition

Cost-benefit analysis is a methodology used to quantify the costs and benefits of a project over a certain period of time, to determine if the project is worth implementing (or continuing). It estimates the net present value of the project by comparing the amount invested today to the present value of the future benefits associated with the investment. Cost-benefit analysis is often conducted for the project of interest and its possible alternative(s), with a view to obtaining comparable estimates that can inform a final decision concerning the project. Table F2.1 summarises the main strengths and weaknesses of cost-benefit analysis.

Fiche 2

Table F2.1: Generic strengths and weaknesses of cost-benefit analysis

STRENGTHS	• well established and transparent approach • systematic review of choices • focus on quantification and comparability
WEAKNESSES	• valuation techniques are imperfect • highly sensitive to assumptions about discount rate • limited ability to incorporate equity considerations

Source: adapted from Pearce *et al.* (2006)

Cost-benefit analysis provides a framework for organising information in support of decisions about the allocation of resources. Its appeal lies in (i) the comparability of the estimates of costs and benefits, as they are all expressed in monetary terms, and (ii) the notion that all perspectives are measured against the same yardstick, thus providing an assessment that reflects the best interest of society as a whole.

Cost-benefit analysis computes net present values. Stated differently, in a cost-benefit analysis paradigm a project should be undertaken if the net present value is positive and higher than that of other, alternative options. Since an investment in the future is usually valued less than an investment today, future costs and benefits are discounted to a present value. The discount rate used generally reflects the foregone return on capital (that is, the return on capital that could have been obtained, had the capital been invested differently).

Cost-benefit analyses can be especially useful for decisions involving non-market goods and services, such as those related to emissions of greenhouse gases: lacking market signals about those goods and services, cost-benefit analysis can be used to estimate the costs

and benefits associated with a project that impacts on the said goods and services. In general, cost-benefit analysis has become commonplace for most public policy decisions with potentially large economic impacts.

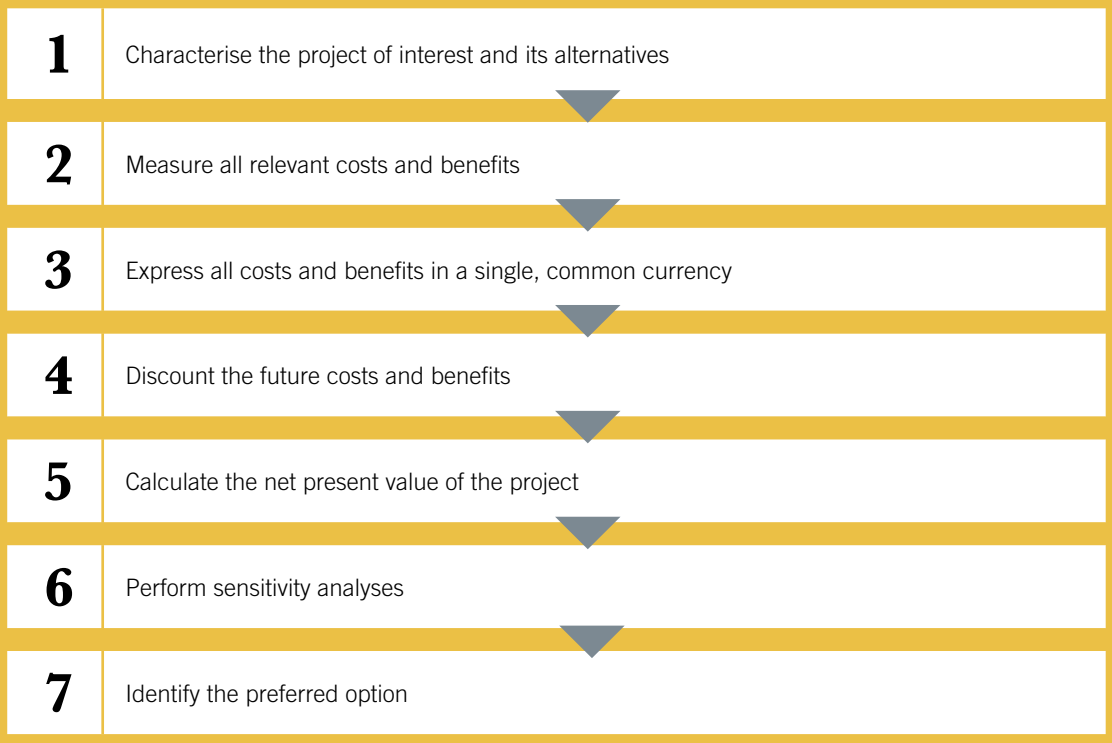
To estimate (in monetary terms) the costs and benefits of non-market goods and services, a range of techniques have been developed. Contingent valuation is one of the most used such techniques. It estimates individuals' willingness to pay (for obtaining a benefit or avoiding a cost), or their willingness to accept (foregoing a benefit or being compensated for a cost). The use of valuation techniques is controversial when it involves ethical issues, such as estimating the costs of a life.

Applications of cost-benefit analysis tend to assume that the value of a given amount of money is the same to both wealthy and poor individuals. As a result, where goods or services are available at below cost, this assumption introduces a bias against lower-income individuals – whether or not they stand to benefit from the project being analysed. Correcting the analysis for income can help remove the bias.

Key steps of a cost-benefit analysis

Figure F2.1 below summarises the main steps involved in conducting a cost-benefit analysis. Although this is a generic representation, most applications would follow all these steps.

Figure F2.1: Steps involved in conducting a cost-benefit analysis



Source: adapted from Boardman *et al.* (2006)

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Stakeholders involved

In a typical cost-benefit analysis stakeholders are engaged at the initial stages – when the project of interest and its alternatives are being characterised. Several methods can be used to engage stakeholders, ranging from quick and targeted consultations, to focus-group discussions or multi-stakeholder workshops, to formal surveys based on more or less detailed questionnaires. The level of stakeholder engagement will depend on the scope of the project and the extent to which it affects the public.

Typical applications and limitations

Cost-benefit analysis can be used to assess the feasibility of a project, to justify investment programmes or identify appropriate cost-reduction strategies, and to quantify hidden costs and intangible benefits. In all these instances costs-benefit analysis acts as an accountability mechanism that helps justify the course of action taken.

In the area of climate change cost-benefit analysis has been used in most sectors, from infrastructure projects, where purely financial criteria, like returns on investment, play a key role in the decision-making process, to projects aimed at accounting for non-market goods and services, such as those involved in afforestation projects, where financial issues play a much less important role. When it comes to the latter, cost-benefit analysis arguably should be complemented with other types of analysis, such as multi-criteria decision analysis.

Typical costs and time frames

A simple cost-benefit analysis, requiring no or limited data collection, no valuation of non-market goods or services, and limited stakeholder engagement can be conducted for a few tens of thousands of United States dollars. At the other end of the cost spectrum, prices can reach one hundred-thousand dollars or more.

The time frames required to obtain data (whether it is existing datasets, or data that needs to be collected), and to consult with stakeholders, determine the duration of the analysis. In general, five to eight weeks are likely to be required even for the simplest of cost-benefit analyses.

For further reading

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (2006). *Cost-benefit analysis: concepts and practice*. Prentice Hall. Upper Saddle River, NJ, United States of America.

Pearce, D., Atkinson, G. & Mourato, S. (2006). *Cost-benefit analysis and the environment: recent developments*. Organisation for Economic Cooperation and Development. Paris, France.

Mishan, E. J., & Quah, E. (2007). *Cost-benefit analysis*. Routledge. London, United Kingdom.

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Multi-criteria decision analysis

Definition

Multi-criteria decision analysis is a methodology for apprising how a range of alternative courses of action perform against individual, often conflicting criteria, and combining the resulting criteria-specific scores into one overall score. Stated differently, multi-criteria decision analysis is a collection of formal approaches, which are used to take explicit account of multiple criteria that matter with regard to a specific decision. Table F3.1 summarises the main strengths and weaknesses of multi-criteria decision analysis.

Fiche 3

Table F3.1: Generic strengths and weaknesses of multi-criteria decision analysis

STRENGTHS	• transparent process that suits governmental accountability requirements • non-monetary and even qualitative information can be considered • outputs are easy to communicate
WEAKNESSES	• deriving weights can be contentious • perceived as being less rigorous than other decision-support tools • stakeholder engagement is crucial and cannot be guaranteed

Source: adapted from Belton and Stewart (2002)

Multi-criteria decision analysis enables the evaluation of options on the basis of pre-established criteria. Unlike cost-benefit analysis, multi-criteria decision analysis does not require that inputs to the analysis are systematically translated into monetary values (or even quantitative values). Whilst cost-benefit analysis remains the most popular decision-support tool, even its proponents acknowledge that multi-criteria decision analysis "may be more comprehensive [than cost-benefit analysis] once goals beyond efficiency and distributional incidence are considered".

Multi-criteria decision analysis has been suggested as particularly well-suited to planning for climate change. Reasons cited include: (i) it allows for an integrated treatment of socio-economic, ecological, institutional and ethical perspectives; (ii) it can take into account issues such as morbidity and mortality, equity, environmental damage, catastrophic risks and uncertainty; and (iii) its application is not limited to areas that can be described fully through monetary values.

In its simplest form, multi-criteria decision analysis scores a number of options (for managing the problem of interest) against a range of indicators. Each indicator reflects the extent to which a criterion considered of importance for the decision is met. The option whose aggregate score is highest will in principle be the most appropriate option for responding to the problem being analysed.

Key steps of a multi-criteria decision analysis

Figure F3.1 below summarises the main steps involved in conducting a multi-criteria decision analysis. Although this is a generic representation, most applications would follow all these steps.

Figure F3.1: Steps involved in conducting a multi-criteria decision analysis

1. Define the boundaries of the analysis
2. Identify performance criteria and associated (quantifiable) indicators
3. Characterise the range of options being compared
4. Score the performance of each option against all indicators
5. Assign weights to each criterion (and group of criteria, if relevant)
6. Calculate overall scores for each option
7. Perform sensitivity analyses
8. Identify the preferred option

Source: adapted from Belton and Stewart (2002)

F3

Stakeholder involvement

A typical government-led application of multi-criteria decision analysis will rely on a consultation with stakeholders. Stakeholders consulted may include government agency staff only, or a broader set of interested parties. Consultations may relate to technical aspects only, or to strategic issues, such as the boundaries of the analysis. A transparent and inclusive process will lend its results more credibility and legitimacy than it would otherwise be the case. Arguably, that combination of credibility and legitimacy is at least as important as the outputs of the analysis themselves.

Typical applications and limitations

Multi-criteria decision analysis is particularly suited for reviewing multi-dimensional decision choices characterised by a mixture of monetary and non-monetary objectives. For example, it has been used to identify nuclear waste disposal sites, to conduct production site analyses for power stations, or in the context of relocation decisions and assessment of public transport systems.

Multi-criteria decision analysis provides a systematic framework through which decision choices can be studied at the level of their various individual components. Such an approach makes it possible to track and document in a transparent manner all decision processes, thus promoting accountable decision-making. As such, multi-criteria decision analysis is an aid to the decision-making process, but its outcomes are seldom used as the sole rationale for a making a decision.

Typical costs and time frames

The costs of conducting a multi-criteria decision analysis mainly depend on (i) the scope of the stakeholder consultation, and (ii) the data requirements associated with the criteria and indicators chosen. An inclusive stakeholder consultation will be more costly to organise, and might even require some form of training for stakeholders, so that they can meaningfully understand both the process and the stakes. Most applications of multi-criteria decision analysis will rely on existing data. Using indicators that require additional data collection efforts will inevitable increase costs.

Unless extensive data collection efforts are considered, a multi-criteria decision analysis can be conducted within a short period of time – for example, two months. Stakeholder availability is likely to be the determining factor with regard to time frames, as the analysis itself can be completed in a matter of days.

For further reading

Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach*. Springer. Berlin, Germany.

UK DCLG (2009). *Multi-Criteria Analysis: a manual. Department of Communities and Local Government*. London, United Kingdom.

UNEP (2011). *A practical framework for planning pro-development climate policies*. United Nations Environment Programme. Nairobi, Kenya.

F3

Annex 1

Life Cycle Assessment as a decision support tool for municipal solid waste management in Iran

Topic	Using life-cycle analysis to support climate change mitigation planning in Iran's waste sector.
Key message	Life-cycle analysis makes it possible to compare different municipal solid waste management options, to determine how each option performs against different decision criteria, including emissions of greenhouse gases.
Source	Mahmoudkhani, R., Valizadeh, B., & Khastoo, H. (2014). Greenhouse Gases Life Cycle Assessment (GHGLCA) as a decision support tool for municipal solid waste management in Iran. *Journal of Environmental Health Science and Engineering, 12*(1), 1.

Solid waste management poses several challenges – economic, social and environmental. From an environmental point of view, the worst practices are those that result in high methane emissions, air pollution, and discharges to water and soil through leachate from open dumped waste. Iran is facing these challenges, as 83 percent of the waste generated in the country is disposed of in landfills without any treatment.

Life-cycle analysis

In an effort to identify a waste management practice that limits emissions of greenhouse gases, the government of Iran conducted a life-cycle analysis of several possible practices. The life-cycle analysis was performed using a computer model developed by the United States Environmental Protection Agency. This model, which is known as Waste Reduction Model, or WARM for short, provides greenhouse-gas emission factors for ten typical waste streams in municipal solid waste systems (for example, paper, plastics or metals). The model makes it possible to calculate polluting emissions for a range of waste treatment alternatives, such as recycling, incineration, composting, or landfilling.

To use the model, the analysists conducting the life-cycle analysis had to collect data on the following topics:

- **Waste streams:** how much waste is generated in the country and to what extent each of the main disposal methods are used?
- **Recyclable waste:** what is the distance between recycling facilities and recycling markets?
- **Landfilled, incinerated and bio-digested waste:** what is the distance between the waste treatment and waste disposal sites?
- **Landfill sites:** how much landfill gas is captured and how is it used (for example, flaring or energy recovery)?

- **Compost waste:** what is the distance from the source of the waste to the composting site?

Scope definition

The goal of this life-cycle analysis was to determine the greenhouse-gas emission reduction potential of different municipal solid waste management alternatives in Iran. Alternatives considered included those in use in the country and a small number of other municipal solid waste management systems of common use elsewhere.

All typical components were analysed for the main waste generation points. Components include waste transportation, sorting and recycling, composting, bio-digestion, and final landfilling. Generation points included households and stores.

Seven scenarios were considered:

1. Reference scenario: This scenario entails open dumping in a mix of unmanaged sites; with all waste sent to landfill and no capture of landfill gas. Dry waste recycling and composting rates are 5.3 percent and 12 percent, respectively.
2. Capture and flaring of landfill gas scenario: In this scenario landfill gas is captured and flared. Recycling and composting rates are 5.3 percent and 12 percent, respectively.
3. Capture of landfill gas with system upgrade: In this scenario landfill gas capture increases to 75 percent, and 35 percent efficiency energy conversion facilities are installed. Recycling and composting rates are 5.3 percent and 12 percent, respectively.
4. Source separation scenario: This scenario entails separation at source of materials for recycling, albeit without improvements at any other point in the system. About 50 percent of the recyclable or compostable material that are currently not being captured would be captured.
5. Recyclable materials source reduction scenario. In this scenario the amount of recyclable materials is reduced at source by a factor of 3.3 percent, while source separation and recycling or composting of materials increases by 50 percent.
6. Source separation and source reduction scenario: In this scenario source reduction increases by 3.3 percent, recycling increases by 5.3 percent, with organic waste sent for composting, increases by 59 percent, landfilling with energy recovery increases by 32 percent, and burning in cement kilns of non-recyclable solid waste.
7. Incineration scenario: In this scenario incineration with energy recovery is used, instead of landfilling.

Assessment

All inputs and outputs of each scenario were considered, with special focus on air and water emissions, and energy consumption. Note that the energy recovered from landfill gas, bio-digestion, waste incineration, or compost production was not included in the analysis, as was considered to be insignificant next to the overall greenhouse-gas emissions balance. Similarly, precise transportation distances were not obtained: rough proxies were considered sufficient.

Data was sourced from municipal waste management projects, and from governmental agencies such as the Rural Organization for Solid Waste Management System. Relevant datasets include population projections,

waste characteristics and composition, waste management applications, characteristics of the main transfer stations and landfill sites, cost calculations for all waste management alternatives, and operational recommendations for landfill sites. Where no local data was available, national average figures were used.

Main results

The study showed that the capture of landfill gas with system upgrade scenario results in the lowest level of greenhouse-gas emissions (0.5 Mt CO_2e). Table A1.1 gives greenhouse-gas emission results for each scenario.

These figures only consider emissions from collection, treatment, and disposal of waste. Emissions associated to the manufacture of the materials contained in the waste products are not considered.

The analysis showed that the highest greenhouse-gas emission reductions are associated to the scenario 'capture of landfill gas with system upgrade', followed by the 'incineration' scenario. In terms of individual waste management practices, recycling showed significant emissions reduction potential, as did composting

Table A1.1 Greenhouse-gas emissions, by scenario

SCENARIO	ASSOCIATED GREENHOUSE-GAS EMISSIONS (MT CO_2e)
Reference	18
Capture and flaring of landfill gas	2,9
Capture of landfill gas with system upgrade	0,5
Source separation	7,0
Recyclable materials source reduction	7,4
Source separation and source reduction scenario	4,8
Incineration	1,8

Concluding remarks

The analysis reveals that the main options for reducing greenhouse-gas emissions in Iran's solid waste management sector are as follows: source reduction, source separation, recycling, landfill gas capture, composting, and incineration. Landfill gas capture, composting, and incineration directly reduce emission from landfills, whereas source reduction, source separation and recycling reduce emissions indirectly – and possibly to a greater extent – by displacing the processing of raw materials.

Appendix: Additional resources

The lists presented below contain some LCA databases[1] and LCA software[2] currently available for users:

Database	Description	Costs free?	Special area if any	Web site
Ecoinvent	Swiss database, over 11,500 LCI databases. Managed by a Swiss not-for-profit association founded by institutes of the ETH Domain and the Swiss Federal Offices.	No	Not mentioned	http://www.ecoinvent.org/
ELCD	JRC of the European Commission, contains more than 300 datasets	Yes	Energy, material production, disposal and transport	http://eplca.jrc.ec.europa.eu/?page_id=126
GaBi Databases	One of the largest databases. It is mainly based on primary data collection.	No	Several industries from agriculture to electronics and retail, through to textiles or services	http://www.gabi-software.com/databases/gabi-databases/
LCA Food	Data on basic food products produced and consumed in Denmark.	Yes	It covers processes from primary sectors such as agriculture and fishery through industrialfoodprocessing to retail and cooking.	http://www.lcafood.dk/
LC - inventories	Created by ESU-Services and other authors. Over 1000 process data sets, which are corrections, updates or extensions of ecoinvent v2.2 database	No	Not mentioned	https://nexus.openlca.org/database/LC-Inventories.ch
GEMIS	Developed by the International Institute for Sustainability Analysis and Strategy (IINAS)	Yes	For biomass, renewable energy, energy efficiency, transport, sustainable land use as well as resource-related material flows and sustainable consumption	http://www.iinas.org/gemis.html
U.S. Life Cycle Inventory (LCI) Database	Created by NREL, US-American database with around 300 datasets	yes	Not mentioned	http://www.nrel.gov/lci/
ProBas	Database of the German Federal Environmental Agency and IINAS	Yes	For energy, material production, transport and disposal	http://www.probas.umweltbundesamt.de/php/index.php
Ökobau.dat	German database with around 950 EPD datasets	Yes	For building materials, building processes and transport processes	http://www.oekobaudat.de/
CPM LCA Database	Developed within the Swedish Life Cycle Center	Yes		http://cpmdatabase.cpm.chalmers.se/

1) Green Delta http://www.greendelta.com/Databases.119.0.html?&L=1

2) A Review of LCA Methods and Tools and their Suitability for SMEs Lehtinen H, Saarentaus A, Rouhiainen J, Pitts M, Azapagic A. Partnerships for Better Innovation Support. Europe Innova, Eco - Innovation, Biochem May 2011. http://www.biochem-project.eu/download/toolbox/sustainability/01/120321%20BIOCHEM%20LCA_review.pdf

A1

Appendix: Additional resources

The lists presented below contain some LCA databases[1] and LCA software[2] currently available for users:

Software	Supplier	Supports LCI and/or LCIA	Supports full LCA	Language	Main database	Special area if any	Free?	If commercial, availability of free trials	Web site
AIST-LCA, Ver.4	National Institute of Advanced Industrial Science and Technology (AIST)		Yes	Japanese	AIST-LCA Database		No	No free trial available	https://www.aist-riss.jp/old/lca/cie/activity/software/aist/outline.html
BEES 4.0	National Institute of Standards and Technology (NIST)		Yes	English	Bees database	Construction industry	Yes		http://www.nist.gov/el/economics/BEESSoftware.cfm
CCaLC Tool	The University of Manchester		Yes	English	CCaLC database including EcoInvent database		Yes		http://www.ccalc.org.uk/index.ph p
	The Danish Technical University DTU	yes	yes	English	Own database, with possibility to import others	Waste management and energy systems	Yes		http://www.easetech.dk/EASEWASTE
Eco-Bat 2.1	Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud	Yes		French, Italian, English	Eco-Bat database	Construction industry	No		http://www.eco-bat.ch/index.php?lang=en
Ecoinvent waste disposal inventory tools v1.0	Doka Life Cycle Assessments (Doka Okobilanzen)	Yes		English	Ecoinvent database	Waste anagement	No	Yes	http://eplca.jrc.ec.europa.eu/ResourceDirectory/faces/tools/toolList.xhtml;jsessionid=0F5F41A5A0FA7E2AC0136EE3B64B7E30
EIME V3.0	CODDE		Yes	English	EIME database	Electrical, mechanical and electronic products	No	Yes	http://www.codde.fr/en/lca-software.com/
Environmental Impact Estimator V3.0.2	Athena Sustainable Materials Institute		Yes	English	Own database	Construction industry	No	Yes	http://www.athenasmi.org/
eVerdEE v.2.0	ENEA - Italian National Agency for New Technology, Energy and the Environment		Yes	Italian, English	ENEA Database		Yes		http://www.ecosmes.net/everdee/login2
GEMIS, version 4.4	Oeko-Institut (Institute for applied Ecology), Darmstadt Office	Yes		Spanish, Czech,-German, English		Energy, transport, recycling and waste treatment	No		http://www.iinas.org/gemis-de.html
LEGEP 1.2	LEGEP Software GmbH		Yes	English, German	LEGEP Database	Construction industry	No	Yes	http://www.legep.de/index.php?AktivId=1125
LTE OGIP; Version 5.0; Build-Number 2092; 12-12-2005	t.h.e. Software GmbH		Yes	German		Construction industry	No		http://www.the-software.de/index.html

continuation

Software	Supplier	Supports LCI and/or LCIA	Supports full LCA	Language	Main database	Special area if any	Free?	If commercial, availability of free trials	Web site
OpenLCA	GreenDeltaTC GmbH		Yes	English			Yes		http://www.openlca.org
Qantis suite 2.0	Quantis		Yes	English	Qantis database		No	Yes	http://www.quantis-intl.com/software.php?step=fonct
REGIS 2.3	sinum AG		Yes	Japanese, Spanish, German, English	ecoinvent Data v1.3:		No	Yes	http://www.sinum.com/en/products/software/
SALCA-tools	Agroscope Reckenholz-Tänikon Research Station ART	Yes		German		Agriculture		Free for tool	http://www.agroscope.admin.ch/
Sankey Editor 3.0	STENUM GmbH	Yes		English			No	Yes	http://www.stenum.at/produkte/en_1b-3a.htm
SimaPro 7	PRé Consultants B.V.		Yes	Spanish, French, Italian, German, English	SimaPro database		No	Yes	http://www.pre.nl/
Umberto 5.5	ifu Hamburg GmbH		Yes	English	Umberto library		No	Yes	http://www.umberto.de/en/produc t/index.htm
WRATE	UK Environment Agency		Yes	English		Municipal waste management systems	No	Yes	http://www.wrate.co.uk/
WISARD	Created by Pricewaterhouse Coopers Eco-bilan Group. It is a LCA software tool to help decision making and evaluate policy options concerning the disposal of household waste.	Yes	Yes	English	Own database	Municipal waste	No		http://www.life-cycle.org/?page_id=125

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Annex 2

Cost-benefit analysis of large-scale solar photovoltaic power generation in Abu Dhabi

Topic	Using cost-benefit analysis in support of policy planning for the deployment of renewable energy technologies.
Key message	Monetising the benefits associated with reductions in airborne pollutants is difficult from an analytical point of view and requires both awareness about the issue on the part of decision makers as well as political will to take those benefits into consideration.
Source	Harder, E., & Gibson, J. M. (2011). The costs and benefits of large-scale solar photovoltaic power production in Abu Dhabi, United Arab Emirates. *Renewable Energy, 36*(2), 789-796.

Abu Dhabi, one of seven emirates in the United Arab Emirates, is endowed with both fossil and renewable energy resources. While continuing to exploit the former, the emirate has set itself a policy goal of developing the latter. In support of the associated policy planning process, in 2011 an analysis was conducted to assess the financial viability of a large (10 MW) photovoltaic power station. A range of different assumptions were used regarding technology costs, electricity prices and greenhouse gas emission reduction volumes, which made it possible to determine the extent to which cost-benefit ratios might vary depending on those assumptions.

Feasibility study

Estimates of likely electricity generation levels were obtained using the RETScreen software[1]. These estimates made it possible to calculate the amount of fossil fuel-generated electricity that the photovoltaic power station could displace and the amount of greenhouse-gas and local air pollutant emissions that could be abated. For this calculation, it was assumed that the electricity generated by the photovoltaic power station would displace electricity generated by a gas-fired power station.

The RETScreen software also provided estimates of likely financial returns. These estimates were used to calculate the net present value of the photovoltaic power station.

1) RETScreen is a software package that facilitates the elaboration of financial studies for energy efficiency, renewable energy and cogeneration projects. The software is freely available online at: http://www.retscreen.net/

Electricity generation

The electricity generation potential of the photovoltaic power station was estimated using solar radiation data at a plausible location for the station, performance data for selected commercial photovoltaic modules and estimates of expected energy losses.[2] On this basis, it was established that, to generate 10 MW of electricity, the station would have to consist of 111,111 photovoltaic modules, covering 69,980 m^2.

Financial costs

Total costs were calculated by adding initial costs, periodic costs, and end-of-life costs.[3] They were estimated at, respectively, USD 92 million, USD 2 million and USD 9 million (Table A2.1).

Table A2.1: Summary of initial, periodic, and end-of-life cost

TYPE OF COST	AMOUNT (THOUSAND USD)
Feasibility study	200
Development	165
Engineering	150
Equipment	55,000
Balance of station costs	36,500
Tracking system	10,500
Inverters	10,000
Electrical components	7,000
Installation	9,000
Total initial costs	92,015
Inverter replacement costs	2,000
Operation and maintenance	335
Total periodic costs	2,335
End-of-life costs	9,202
Total End-of-life costs	9,202

Source: adapted from Harder and Gibson (2011)

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2) Energy losses are caused by high temperatures and the accumulation of dust and sand on the photovoltaic modules. The photovoltaic modules are less efficient when temperatures increase beyond 45 °C. At these temperatures, for each additional degree centigrade electricity output is reduced by 0.4 percent. On the basis of the existing literature, it was assumed that sand and dust would decrease annual electricity generation levels by 5 percent, compared to 'optimal' conditions. Conversion from direct current (generated by photovoltaic modules) to alternative current (suitable for distribution through the electricity grid) was estimated to cause a further loss in performance. This loss was estimated as 5 percent below the levels that could be reached if conversion were not necessary.

3) Individual estimates were taken from the literature.

Equipment costs were based on a module price of USD 5.50 per Watt. It was assumed that the up-front investment to construct the station could be covered without a loan. As the United Arab Emirates do not have a tax system at present, all taxes were assumed to be zero.

Financial benefits

The price that the photovoltaic power station can expect to receive for the electricity it exports to the grid (so called electricity export rate) is estimated at USD 0.082 per kWh. This price is expected to increase by 4 percent per year over the station's lifetime. Assuming an annual inflation rate of 2.5 percent and applying a nominal discount rate of 5 percent, the expected income from the sale of electricity during the station's lifetime is estimated at USD 51.8 million.

Balance

The initial costs of the plant and the revenues from the sale of electricity are the factors with the largest impact on the plant's financial feasibility (Table A2.2). On the basis of the assumptions outlined above, the plan would be unattractive from a financial viewpoint.

Energy production costs were estimated at USD 0.16 per kWh, which is almost double the assumed value for the 'electricity export rate'. It follows that the station would have to be operational for over 55 years (almost double its assumed lifetime) for the investment to pay back. Stated differently, if the assumed lifetime and the value of the 'electricity export rate' remain unchanged, the station would only be financially attractive if the initial costs could be kept below USD 41 million.

Table A2.2: Elements of the station's net present value

	AMOUNT (THOUSAND USD)				
	Initial costs	Income	Operation and maintenance	Inverter replacement	End-of-life costs
Amount (million USD)	92.0	51.8	7.1	8.0	4.5

Source: adapted from Harder and Gibson (2011)

Sensitivity analyses

The results of the analysis outlined in the previous paragraphs are based on a set of assumptions about likely future developments in key variables (these are the variables that affect most the financial and technical performance of the power station). Those 'likely future developments' are uncertain, in

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that we cannot know which conditions will actually come to pass within the time frames concerned. For this reason, it is instructive to consider several possible future conditions and re-run the analysis using alternative values for our assumptions, to determine the extent to which different – but in principle equally plausible – 'likely future developments' might change the results of the analysis (Table A2.3).

Electricity generation

Using different measurement locations, a second study of solar radiation estimated an electricity generation potential that is 7.8 percent lower than that estimated by the study considered initially. With regard to energy losses, two different rates were used (2 percent and 10 percent), one higher and one lower than the rate of 5 percent used initially.[4]

Table A2.3: Summary of the sensitivity analyses conducted

INPUT VARIABLE	VALUE CHANGE		RESULTS (percent change from original)		
	Original value	New value	Net electricity generation (GWh)	Production costs (USD cent per kWh)	Net present value (USD million)
Global solar radiation (kWh/m²/day)	5.97	5.58	22.3 (-7.8 %)	16.9 (-4.4 %)	-53.2 (-4.6 %)
Electricity escalation rate (percent)	4	8	no change	8.8 (-45.6 %)	-7.2 (+85.8 %)
Losses from dust and sand (percent)	5	10	23.2 (- 4.5 %)	17.1 (+5.7 %)	-53.6 (-5.1 %)
Initial costs (USD million)	92	65.5	no change	12.0 (-25.8 %)	-24.4 (+52.1 %)
Electricity export rate (USD cent per kWh)	8.16	42	no change	no change	163.7 (+421.9 %)
Market value of greenhouse-gas emissions reduction credit (USD per tonne of greenhouse-gas emissions)	0	16	no change	15.6 (-3.6)	-47.4 (+6.8 %)
Total social benefits stemming from reduced greenhouse-gas and local air pollutant emissions (USD million)	0	47.4	no change	8.66 (-46.5 %)	-3.1 (+93.9 %)

Source: Harder and Gibson (2011)

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4) This refers to losses caused by dust and sand. Losses caused by conversion from direct current to alternative current were not considered in the sensitivity analysis.

Financial costs

Solar photovoltaic modules have seen a sharp decline in costs over time. An estimate of USD 3.33 per Watt (instead of USD 5.5 per Watt, the figure used initially) was used in the sensitivity analysis.

Financial benefits

In 2007 the United Arab Emirates became net importers of natural gas. In this situation it appears sensible to assume that the 'electricity export rate' would increase. For the sensitivity analysis a value of USD 0.42 per kWh was used, instead of the much lower estimate (USD 0.082 per kWh) used initially. Further, the so-called electricity escalation rate (the assumed escalation in electricity prices per year over the lifetime of the power station) was assumed to increase from 4 percent to 8 percent.

Environmental benefits

The construction of the photovoltaic power station would replace 24.4 GWh of annual thermal power generation, saving 10,732 tonnes of carbon dioxide equivalent, 372.8 tonnes of nitrogen oxides, 0.15 tonnes of sulphur dioxide, and 1.7 tonnes of suspended particulates. Stated differently, compared to electricity generated in a natural gas-fired power station, photovoltaic-powered electricity generation results in lower emissions of greenhouse gases and local air pollutants. Such reduced emission levels represent a 'social benefit' that arguably warrants inclusion in the cost-benefit analysis. To this end a separate analysis was conducted to monetise those social benefits.

The initial analysis assumed that savings in greenhouse-gas emissions would have no monetary value. Yet, through the Kyoto Protocol's flexible mechanisms, Abu Dhabi had successfully secured climate finance for emissions saved through similar solar energy-powered projects.[5] Using a 5 percent escalation rate for 20 years, the financial benefits associated with the trading of greenhouse-gas emission reduction credits would increase the net present value of the power station by 6.8 percent, compared to a situation in which emissions trading is not considered.

The scientific literature provides unit cost estimates of the damages (to human health, among others) associated with emissions of local air pollutants and greenhouse-gases. Using these unit costs, the monetary value of the avoided emissions was estimated. Assuming an annual discount rate of 2.5 percent, the net present value of the power station increased by 93 percent, compared to the initial analysis.[6]

Since the discount rate plays such a prominent role in the calculation of 'avoided social damages' and given that both lower and higher discount rates have been advocated in the literature, two alternative values were also applied: 1 percent and 4 percent. Using these, the net present value of the benefits associated with reduced greenhouse-gas and local air pollutant emissions ranged from USD 221 million to USD 0.4 million.

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5) At the time the analysis was conducted (2010), greenhouse-gas emission reduction credits were sold at USD 16 per tonne of carbon dioxide equivalent.

6) This discount rate is consistent with the rate applied in the RETScreen software (see above).

Conclusions

The initial calculations showed that the power station's net present value would be negative. The sensitivity analyses identified a set of factors that could increase the project's financial viability (most notably, updated solar photovoltaic module prices or estimates of electricity prices).

Nonetheless, only the benefits associated with reductions in airborne pollutants justify the project from a financial viewpoint. Estimating those benefits is challenging and requires a certain level of awareness on the relevant decision-makers, as well as willingness to consider this kind of benefits, which seldom feature in mainstream financial decisions.

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Annex 3

Multi-criteria decision analysis and cost-benefit analysis in the power sector in Greece

Topic	Comparing the results of multi-criteria decision analysis and cost-benefit analysis in the context of policy planning for the electricity sector.
Key message	By using both multi-criteria decision analysis and cost-benefit analyses to assess the same problem, it is possible to capitalise on the strengths of each method, while increasing the robustness of the results when, as is the case in this example, both methods give the same results.
Source	Diakoulaki, D., & Karangelis, F. (2007). Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews, 11*(4), 716-727.

In the early 2000s the government of Greece released four scenarios of electricity generation in the country. Among other issues, the scenarios differed on the share of renewable energy sources in the electricity mix by 2010. To determine which scenario would offer the best compromise in terms of economic, technical and environmental performance, two analyses were conducted – one using multi-criteria decision analysis and the other using cost-benefit analysis. The goal of relying on two decision-support techniques instead of one was to compare the results obtained through each technique, as a means of understanding better the trade-offs associated with adopting any one of the four scenarios considered. Specifically, the analysis sought to explore how the scenario that includes a high share of renewable energy compares with the other three scenarios.

Scenarios considered

The study considered four scenarios, all assuming approximately the same increase in generation capacity in the period between 2000 and 2010. The main features of each scenario can be summarised as follows:

- The Regulatory Authority for Energy, the energy regulator in Greece, developed a 'reference scenario' (hereinafter, BAU). This scenario assumed a continuation of the trends that dominated electricity generation in Greece in 2000, but including the implementation of newly approved policy measures.
- The Public Power Corporation, the biggest electric power company in Greece, developed a scenario that reflects the company's business plans (hereinafter, PPC). The scenario is instructive in that it covers the entire sector, including expected investments by other market players.
- The National Observatory of Athens, a research centre, developed a so-called climate change abatement scenario

(hereinafter, CCA). Compared to the 'reference scenario' (see above), this scenario assumes a higher share of renewable energy and natural gas in the fuel mix.

- The Regulatory Authority for Energy also developed a second scenario, dubbed 'unsteady conditions' (hereinafter, USC). This scenario assumes a faster increase in electricity demand, compared to the 'reference scenario', as well as the exploitation of domestic lignite deposits.

Additions in renewable energy generation capacity in the period between 2000 and 2010 are highest in the CCA scenario (2,120 MW), followed by PPC (1,720 MW), BAU (1,170 MW) and USC (950 MW). In spite of the increase in renewable energy generation capacity, none of the scenarios meets European Union requirements with regard to the minimum share of renewable sources of energy in electricity generation.[1]

Evaluation criteria

The scenarios are evaluated against three sets of criteria – economic, technical and environmental. Key components of each set of criteria are outlined in the following paragraphs.

The economic criteria assess the extent to which implementing a given option represents an optimal allocation of financial resources and reduces costs to electricity consumers. Individual criteria include: total investment costs associated with increases in generation capacity up to 2010, and electricity production costs.[2]

The technical criteria assess the extent to which electricity supply can be guaranteed at any given time. Individual criteria include: electricity production that can be completely guaranteed, even in dry periods or in periods when wind power generation is low; the ability to respond to peak loads; and the security of supply.[3 4]

The environmental criteria assess the extent to which implementing a given option can hamper the country's ability to meet its national commitments toward the protection of the natural environment. Individual criteria include: relative increases in carbon dioxide emissions in the period 1990-2010; and annual emission levels of sulphur dioxide and nitrogen oxides, the two main acidifying gases.

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1) European Union Directive 2001/77/EC requires that renewable sources of energy contribute by just over 20 percent to electricity generation in Greece in 2010. In the CCA scenario renewable energy contributes by 17.5 percent, while the share reaches only 10 percent in the BAU scenario.
2) Electricity production costs comprise initial investments (to which an annual discount rate of 8 percent is applied), depreciations, fuel costs and maintenance costs.
3) The ability to respond to peak load is calculated by assigning pre-defined coefficients to each energy source: 1 to the installed capacity of natural gas, oil and large hydro units; 0.5 to lignite-powered electricity generation (lower than that of natural gas, oil and large hydro, because lignite is used normally at base load, as it is not able to quickly respond to higher demand during peak hours); and 0 to wind and small hydro.
4) The security of the system's supply is calculated by assigning pre-defined coefficients to each energy source: 100 to domestic lignite and renewable sources of energy, 40 to natural gas, and 20 to oil. This breakdown reflects both geopolitical factors and energy endowments.

When each scenario is scored against the above criteria, the trade-offs associated with choosing any one scenario become apparent (Table A3.1). For example, the BAU scenario scores high on both economic criteria, but rather poorly on the environmental criteria. Similarly, the USC scenario scores high in all technical criteria, but its performance with regard to most other criteria is poor.

Table A3.1: Performance of each option in 2010 against the chosen criteria

Criteria	SCENARIOS			
	BAU	PPC	CCA	USC
Investment cost (EUR million, 2004)	5,138	5,323	5,447	6,020
Production cost (EUR per MWh)	52.38	52.36	53.03	53.13
Guaranteed electricity (GWh)	73,130	66,830	60,260	74,390
Peak load power (MW)	12,793	12,416	12,122	12,789
Security of supply (qualitative)	72	70.9	76.3	77.2
Carbon dioxide emissions (percent change from 1990)	69.8	48.0	30.8	86.5
Sulphur dioxide emissions (kt)	466	398	322	541
Nitrogen oxides emissions (kt)	90	77	67	102

Source: adapted from Diaoulaki and Karangelis (2007)

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Multi-criteria decision analysis

Different methods exist to compare among the scores of different options. In this study the so-called outranking method was used. This method entails the pairwise elimination of 'outperformed' options. The option that is not 'outperformed' by any other is considered the best option.

Prior to calculating scores, four sets of weights were defined. The first set gives equal importance to all three categories of criteria – economic, technical and environment. Sets 2, 3 and 4 give a weight of 50 percent to the economic, technical and environmental criteria, respectively. Within a set of criteria, the allocated weight is distributed equally among the individual criteria.[5]

All four scenarios (Table A3.1) are compared with one another at the level of the individual criteria. In this pairwise comparisons, a value of 1 (preference) or 0 (no preference) is obtained for each criterion.[6] These values are then aggregated, taking the weights into account, to obtain a single value that characterises the extent to which one option 'outperforms' the other in that particular pairwise comparison. The process is repeated for all possible combinations of pairwise comparisons, to obtain a single 'index' for each option (Table A3.2).[7]

The results of the analysis (Table A3.2) show that, irrespective of the set of weights chosen, the CCA scenario appears to be the most favourable option, followed by the PPC, BAU and USC scenarios. Interestingly, CCA is the scenario that envisions a highest share of renewable energy in electricity generation, followed by – as above – the PPC, BAU and USC scenarios.

Table A3.2: Outranking indices for scenarios, by set of weights

	SET OF WEIGHTS			
SCENARIO	Set 1	Set 2	Set 3	Set 4
CCA	0.13	0.12	0.13	0.26
PPC	0.05	0.05	0.04	0.07
BAU	– 0.06	– 0.04	– 0.04	– 0.09
USC	– 0.18	– 0.13	– 0.13	– 0.24

Source: Diaoulaki and Karangelis (2007)

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5) For example, in the second set of weights the economic set of criteria receive 50 percent of the total weight. Since the economic set of criteria consists of two criteria, each individual criterion will receive 25 percent of the total weight (that is, the 50 percent weight is distributed equally between those two criteria).

6) For any one criterion, a difference of performance below 10 percent is considered non-significant.

7) In this application, four different indices are obtained for each option. This is because four sets of weights have been defined, which requires that the entire process is performed four times – one for each set of weights.

Cost-benefit analysis

To conduct the cost-benefit analysis it is necessary to re-define the criteria, so that the performance of any one option against any one criterion can be expressed in monetary terms. This only applies to the technical and environmental criteria, as the 'default' version of economic criteria is already defined in monetary terms.[8]

The criterion 'guaranteed energy supply' is redefined in monetary terms by calculating the difference in score between the scenario being considered and the scenario that scores highest (the USC scenario), and multiplying that difference by a unit cost of EUR 30 per MWh.[9] Note that the difference in score corresponds to additional electricity imports.

The criterion 'power available during peak load' is redefined in monetary terms by calculating the difference in score between the scenario being considered and the scenario that scores highest (the BAU scenario), and multiplying that difference by the unit cost of back-up units working at a 0.15 load factor, which are assumed to have generation costs that are 50 percent higher than those of regular generating units.[10] Note that the difference in score corresponds to the loss in power during peak load.

The criterion 'emissions of carbon dioxide' is redefined in monetary terms by calculating the excess in emissions with respect to the national target and multiplying that difference by a price of EUR 10 per tonne of carbon dioxide.

Table A3.3: Costs elements and total costs, by scenario

	SCENARIOS			
COST COMPONENTS	BAU	PPC	CCA	USC
Electricity production	3,966	3,538	3,364	4,097
Electricity deficit	38	227	424	0
Peak power deficit	0	40	71	0
Carbon dioxide emissions	288	198	127	357
Sulphur dioxide emissions	1,862	1,593	1,287	2,164
Nitrogen oxides emissions	448	385	333	512
Total costs	**6,602**	**5,981**	**5,606**	**7,130**

Source: Diaoulaki and Karangelis (2007)

Note: all cost components refer to the target year (2010) and are calculated on the basis of the assumptions in each scenario concerning electricity generation in that year

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8) The criterion 'security of supply' cannot be redefined in monetary terms, because no generic cost estimates are available.
9) This unit cost corresponds to the market price for electricity imports in the Balkans (at the time the study was conducted).
10) These units are assumed to be fuelled by natural gas in a combined cycle power station.

The criterion 'emissions of acidifying substances' is redefined in monetary terms by calculating the excess in emissions with respect to national targets for sulphur dioxide and nitrogen oxides. The differences are multiplied by EUR 4,000 per tonne (for sulphur dioxide) and EUR 5,000 per tonne (for nitrogen oxides).[11]

With regards to the economic criteria, it is worth noting that the investment cost is considered only in its annualised form. This corresponds to the form in which the criterion is quantified in the context of the multi-criteria decision analysis.

The CCA scenario has the lowest annual private cost (Table A3.3). This is mainly because the envisaged electricity output is lowest in this scenario. The PPC scenario shows the second lowest cost. A key difference in overall performance between these two scenarios stems from their respective performance at the level of the individual environmental criteria. From this point of view, the higher share of renewable sources of energy in the CCA scenario contributes significantly to its overall superior performance.

Sensitivity analyses are run for three parameters.[12] The results remain unchanged, with the CCA scenario showing the lowest private costs.

Concluding remarks

Both methods show that, against the criteria chose and assumptions made, the CCA scenario represents the best of the four options, followed by the PPC scenario. This application highlights that, while the approaches obviously differ, both multi-criteria decision analysis and cost-benefit analysis can provide a policy-relevant, single indicator of performance.

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12) These parameters are: the cost of electricity imports increases to EUR 50 per MWh; the cost of purchasing carbon dioxide emission allowances increases to EUR 20 per tonne of carbon dioxide; and the cost of the damages associated with emitting sulphur dioxide are EUR 2,000 per tonne, while the corresponding costs for nitrogen oxides are EUR 2,500 per tonne.

Decision-support tools for climate change mitigation planning

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The UNEP DTU Partnership (UDP) is a leading international research and advisory institution on energy, climate change and sustainable development. UDP is a so-called collaborating centre of the United Nations Environment Programme (UNEP). In this capacity it supports the delivery of UNEP's climate change activities. In addition, UDP works with other multilateral and bilateral agencies on energy, climate change and sustainable development projects.

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