Assignment week 1: Energy efficiency policy evaluation and MCA

Teachers
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Targets
- Get hands-on experience on indicators for evaluating technical measures and policy measures
- Understand the possibilities and limitations of these metrics

Final product
A report not exceeding 10 pages (excluding tables) in Word or pdf. This part should be self-explanatory, i.e. without links to Excel. Please explain how you did the calculations. Your mark will be based on this report. However, you have to send your Excel sheet as well. Make sure that it is well-organised and easy to check, by using different colours, naming of parameters and table captions, appropriate units and so on.

Group size: 2 persons per group

Background literature
- K. Blok and E. Nieuwlaar, Introduction to Energy Analysis. 2nd and 3rd edition, Routledge editors, 2017 and 2021 (available as e-book at ISE's library):
  - Sections 11.3 to 11.5 on cost-benefit analysis
  - Chapter 12 on energy efficiency potentials

- Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers. US-EPA. 2008. https://19january2017snapshot.epa.gov/sites/production/files/2015-08/documents/understanding_cost-effectiveness_of_energy_efficiency_programs_best_practices_technical_methods_and_emerging_issues_for_policy-makers.pdf

Deadline
- Wednesday, 28 February 2024, 17:00
- Upload your assignments (Word/pdf and Excel document) on Moodle
- Debriefing: Friday, 1 March 2024, 8:15

Introduction

When evaluating energy efficiency measures and energy efficiency policy measures, **effectiveness and cost effectiveness** are important key performance indicators (KPIs):
"Effectiveness" addresses the question to what extent technical measures or a policy instrument contribute to reaching a policy goal. To answer this question, "we must first determine to which extent the pre-set goal was achieved. This does not answer the question of effectiveness yet, since autonomous developments, other policies, or external factors, may have contributed to achieving the goal, too. The effectiveness of a policy instrument is the degree to which the policy instrument itself contributed to the achievement of the goal: to determine this, we must compare the achievement reached with the policy in place, with what would have been achieved had the policy "**not been in place**" (the latter is typically described as reference, reference development, reference case, baseline etc.) (explanation largely taken from K. Blok, section 14.3). This approach of comparing the additional effect of a policy measure compared to its non-existence is also called **"additionality".**

Cost-effectiveness and cost-benefit analysis quantify the "efficiency" of technical measures or of a policy measure by comparing the costs and the energy savings (or other benefits; see below) in the form of a ratio. The terms, "cost-benefit analysis" and "cost-effectiveness" are often used interchangeably. Depending on the context, also Levelized cost analysis (e.g., of energy savings) or annual(ized) cost analysis are used as synonyms. The cost-benefit ratio or the cost-effectiveness of an energy efficiency measure may be determined by dividing the costs of technical/policy measures (in CHF per year) by the energy savings (in kWh electricity per year) or avoided energy costs (in CHF per year); instead of the latter, the inverse, i.e. the Benefit-Cost Ratio (in CHF per year/CHF per year), may also be determined. Both the costs and the energy savings are expressed relative to a reference case (typically a business-as-usual case). Further examples are to divide the costs of technical/policy measures by avoided emissions (also referred to as emission abatement costs or emission mitigation costs) or by avoided external costs (e.g., generation capacity, transmission and distribution capacity). The avoided emissions and the avoided external costs are calculated as difference between the new situation after implementation of measures and the previous situation (reference case).

At the level of individual energy efficiency measures the table below provides an overview of different approaches of determining the **additionality** of costs and the additionality of impacts (i.e., energy savings). By applying these approaches we try to make sure to measure the "true" effect of the policy measures (i.e., their "additional" effect), thereby excluding other influencing factors (e.g., autonomous technical progress).

Table A): **Table 4-5. Defining Costs and Impacts of Energy Efficiency Measures**

	Type of Measure	Measure Cost ($/Unit)	Impact Measurement (kWh/Unit and kW/Unit)
1.)	**New** New construction Lost opportunity	Cost of efficient device **minus** cost of standard device *(Incremental)*	Consumption of standard device **minus** consumption of efficient device
2.)	**Replacement** Failure replacement Natural replacement Replace on burnout	Cost of efficient device **minus** cost of standard device *(Incremental)*	Consumption of standard device **minus** consumption of efficient device
3.)	**Retrofit** Early replacement *(Simple)*	Cost of efficient device **plus** installation costs *(Full)*	Consumption of old device **minus** consumption of efficient device
4.)	**Retrofit** Early replacement *(Advanced)**	Cost of efficient device **minus** cost of standard device **plus** remaining present value	*During remaining life of old device:* Consumption of old device **minus** consumption of efficient device *After remaining life of old device:* Consumption of standard device **minus** consumption of efficient device
5.)	**Retire**	Cost of removing old device	Consumption of old device

* The advanced retrofit case is essentially a combination of the simple retrofit treatment (for the time period during which the existing measure would have otherwise remained in service) and the failure replacement treatment for the years after the existing device would have been replaced. "Present Value" indicates that the early replacement costs should be discounted to reflect the time value of money associated with the installation of the efficient device compared to the installation of the standard device that would have occurred at a later date.

Source: US-EPA, Understanding Cost-Effectiveness of Energy Efficiency Programs, 2008

Since investment costs (for households we may rather call these purchase costs) for an energy efficient device occur at a given moment in time while the savings of energy costs (and possibly also of operational costs) are recurring, we annualize the investment cost. For the first two cases listed above, we hence determine the cost-effectiveness as follows:

Levelized costs (LC) = Annualized costs of a technology i:

$LC_i = \alpha \cdot I_i + C_{yearly,\,i}$ (CHF/year) (Eq.1)

$= [\, I_i + (C_{yearly,\,i} / \alpha)\,] \cdot \alpha = (- NPV) \cdot \alpha$

with

i Technology i, i.e. energy efficient technology (EE) and reference technology (REF) respectively

α Annuity factor (unitless)

$$\alpha = \frac{r}{1-(1+r)^{-L}} \quad \text{(Eq.2)}$$

r Discount rate

L Lifetime of the equipment

I Investment costs (CHF)

C_{yearly} Yearly costs, i.e. energy costs and operation & maintenance costs CHF/year)

Cost effectiveness $= ((LC_{EE} - LC_{REF}) – B) / (En_{REF} - En_{EE})$ (CHF/GJ) (Eq.3a)

$= (\Delta (\alpha \cdot I_i + C_{yearly,\,i}) - B) / \Delta En_i$ (Eq.3b)

En_i Yearly energy use of technology i (GJ/year)

B Annual benefits (CHF) of making the transition from the energy efficient technology (EE) and reference technology (REF).
Note: The economic benefit due to reduction of energy demand (energy related cost saving) is evaluated by the difference of Levelized cost (LC) of both technologies. The parameter B (annual benefits) refers to “other benefits” (e.g., health-related ones, taxes etc).

Question 1: Cost-effectiveness at the technology measure level (22 points)

1a) (8 points) The central heating system of a large building has broken down and cannot be repaired anymore. The owner is considering to not only replace the heating system but also the circulation pumps which are still functioning but are beyond their lifetime and hence have no (formal) economic value. The alternative would be to replace only the heating system while keeping the old circulation pumps in use. Note that for both the heating system and the circulation pumps more efficient designs are available today. Table 1 and 2 provide data for different efficiency classes of heating systems and circulation pumps. Please make use of the equations and the table above as well as the data provided below in order to develop one energy efficiency cost curve which consists of these two measures (heating replacement and circulation pump replacement) and shows the cumulative annual potential energy savings and their cost effectiveness if the user chooses an **efficient system instead of a standard system** for replacing the old system. You may make use of the Excel template which, if correctly filled, yields an energy efficiency cost curve with two steps; instead, you may also draw a scaled graph by hand.

Please assume:
Lifetime: 13 years
Discount rate: 8%
Energy Price: 45 CHF/GJ
Investment costs in Table A and B include equipment price and installation.

Table 1: Techno-economic data for different heating systems

Heating systems	Investment (CHF)	Energy demand (GJ/yr)	
H1	55 000	2200	Old
H2	60 000	2100	Standard
H3	110 000	1800	Efficient

Table 2: Techno-economic data for different circulation pumps

Circulation pumps	Investment (CHF)	Energy demand (GJ/yr)	
CP1	18 500	1510	Old
CP2	21 500	1470	Standard
CP3	30 500	1440	Efficient

*Investment costs in table 1 and 2 are expressed in this year's prices.

1b) (2 points) Draw another curve in which you assume that the energy price has been reduced to 20 CHF/GJ.

1c) (6 points) The owner of the neighboring building comes to know about the plans and decides to replace his own heating system (in order to save energy) although it is only five years old. He is undecided whether to additionally replace the circulation pumps and therefore asks you to prepare an energy efficiency supply curve representing his situation. Please examine the impact of energy efficiency measure)(if the old system is replaced with an energy efficient system rather than a standard system. Please prepare such a curve by applying method 4. In Table A above extracted from U.S. EPA report (i.e., **Advanced method** for retrofit), thereby assuming that the remaining present value of the old device is determined by **linear depreciation over the lifespan**.
- Assume the original energy price of 45 CHF/GJ.

Hint 1: Start by filling table section C22:C25 and then proceed to row 9 and row 16.
Hint 2: When calculating potential energy savings, be careful with timing. The energy savings during the remaining time for which the old measure could have been used and that for the rest of the lifetime of the measure should be considered separately.

1d) (2 points) Based on a comparison of your results, what do you conclude about the cost-effectiveness of the replacement of an old system as opposed to early replacement? Explain for an energy price of 45 CHF/GJ.

1e) (2 points) In questions 1a) to 1d) we took a microeconomic perspective, i.e. the perspective of an owner or a businessman. In macroeconomics, the economy as a whole is studied. For example, price elasticities (of demand) are used to describe how energy demand changes as a function of changing prices. Full "reactivity" to energy prices would imply an elasticity of -100% whereas much lower values are typically observed in the energy domain. Assume a price elasticity of -25%. Assume also that the transition from Heating System 1 (H1) to heating System 3 (H3) is aimed for (as typical, nationwide case). Which energy price increase (in %) would you expect to be necessary based on the abovementioned elasticity?

1f) (2 points) Based on your answers to question 1a) to 1d), what should policy makers incentivize? Distinguish the following two cases, i.e.

i. The policy makers pursue an economic rationale.
ii. The policy makers' objective is to maximize effectiveness, i.e. maximize energy savings.

Add a brief reflection of the main barriers to energy efficiency improvement and how they can be overcome by policy measures.

Question 2: Conducting cost-benefit analysis of energy efficiency programs (18 points)

Background related to Question 2: To calculate the cost-effectiveness of energy policies from the government's perspective, we generally apply four steps which are explained in the following.

Step 1: First sum up all the government spending. This can include the costs of the policy program (e.g., subsidies) and the total personnel costs. To keep cost-effectiveness calculations simple, assume that all government costs (including the yearly personnel costs) are spent in the first implementation year of the policy program.[1]

Step 2: Calculate the annualized government costs
To calculate the annualized government costs, the government spending must be distributed over the lifetime of the environmental measure. By doing so we account for the fact that the government is benefiting over several years from its once-only spending.

Step 3: Calculate or estimate the net annual environmental effects (GJ of energy saved or tonnes of avoided CO_2 emissions). The net or additional environmental effects of the policy are obtained by an impact assessment study of the policy. Note that there is difference between the annual savings of an energy efficiency measure and the total savings over the lifetime of the measure.

Step 4: Calculate the cost-effectiveness of the policy by dividing the annual costs by the net annual environmental effect:

$$Cost - effectiveness\ (energy\ savings) = \frac{\alpha \cdot I}{\Delta E}$$

$$Cost - effectiveness\ (CO2\ mitigation) = \frac{\alpha \cdot I}{\Delta M_c}$$

$$\alpha = \frac{r}{1-(1+r)^{-L}}$$

Where:
- α = annuity factor, sometimes also referred to as capital recovery factor
- I = initial investment
- r = discount rate
- L = lifetime of the environmental measures or the depreciation period
- ΔE = annual saved energy
- ΔMc = annual avoided amount of CO_2 (tonnes)

What lifetime or depreciation period should be used?
The lifetime can be set equal to the technical lifetime of the equipment, but a more conservative (shorter) economic lifetime (e.g., 10 years) is also often used.

What discount rate should be used?

[1] It would be more accurate to deflate the cost incurred by government in each year (i.e. to determine the respective values in real terms for a chosen year) and to subsequently add up the deflated costs.

While discount rates for the **private** sector represent the returns from capital investment related to the manufacture of goods or related to the supply of services, **social** discount rates encompass the returns for society as a whole. Social discount rates include the returns of the private sector but in addition, they also account for societal expenses, e.g. for healthcare and environmental pollution. Social discount rates are therefore bound to be smaller than private discount rates. Typical discount rates used for government investments in industrialized countries are 4-6% (formerly 0-2%), while private discount rates as applied in companies may be 10-15% (formerly 5-10%).

See: K. Blok and E. Nieuwlaar. Introduction to Energy Analysis. Routledge editors

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In this exercise you are going to evaluate the cost-effectiveness of energy policy instruments from a governmental point of view. Firm A can implement 8 different energy saving measures. The following table shows the energy savings and the investment costs. Assume a discount rate of 5% and an economic life time of 10 years.

Measure	Investment Costs (1000 €)	Annual Energy savings (TJ)
1	20	1
2	25	1.5
3	30	1.5
4	45	2
5	60	2
6	70	3.5
7	85	5
8	100	6

2a) (3 points) Calculate how much energy can be saved from a microeconomic (private) perspective: you should assume that firm A aims to reduce its risk when implementing profitable energy saving measures. To this end, only investments that have a payback period (PBP) of 4 years or less are made. Neglect operation and maintenance costs. The energy price is 5 € / GJ. The (simple) pay-back period is defined as:

$$PBP = \frac{I}{B - C}$$

in which;
I = investment
B = annual benefits
C = annual costs

2b) (2 points) Calculate what the effect is on the amount of energy savings if the government provides a subsidy of 25% on the capital cost (How much additional savings are caused by this subsidy)?

2c) (2 points) What is the total amount of subsidies (€) that the government has to pay?

2d) (2 points) What is the amount of subsidies that the government has to pay on the additional investment that would not have been implemented without the subsidy?

2e) (2 points) Calculate the free rider effect of the investment subsidy of 25%:

Free rider effect = (subsidies for investments that would have been taken anyway) (€) */ total government subsidies* (€)

2f) (2 points) Calculate the cost-effectiveness of the subsidy scheme from a government point of view. Assume a discount rate of 5% and an economic life time of 10 years. Compare your result to the energy price. What do you think?

Cost-effectiveness (€/GJ)
= annual government costs / additional annual savings = $\alpha \cdot I / \Delta E$

2g) (2 points) Repeat questions b to e for a subsidy scheme of 50%. What do you conclude?

Question 3: Salient features of the EED (10 points)

Please look up the "EED", the European Union's new Energy Efficiency Directive (EU/2023/1791) and read Article 3 on page 32-33.

3a) (8 points) Please list in the form of bullets the most important guiding principles (which are subsumed as "Energy efficiency first principle").

3b) (2 points) One of the guiding principles is "subsidiarity" (you can include this as one of your bullets). Which paragraph in Article 3 addresses the principle of subsidiarity?

Question 4: Multicriteria Analysis (10 points)

Please prepare a Multicriteria Analysis (MCA) for the following electricity generation technologies: Solar PV, Wind onshore, Biomass and Natural gas:

- Summarize your input data (along with the sources) in a table and present your results in the form of a stacked bar diagram.
- Discuss in a few bullet points the impact of your choices (if you find it helpful you may compare your results with those of a co-student in order to better understand the impact of different choices; however, you should not present your co-student's results).

The input data below originate from Maxim (2014).

Table 3
LCOE ($/MW h) for various technologies

LCOE—5% discount rate	
Technology	***LCOE*** **($/MW h)**
Hydro (large)	26.35
Geothermal	39.98
Nuclear	53.79
CHP	62.81
Coal	64.37
Biomass	72
Wind (onshore)	76.28
Natural gas	78.06
Piston engine	104.63
Hydro (small)	124.97
Wind (offshore)	128.68
Solar thermal	177.80
Fuel cell	181.17
Solar PV	202.94

Note: LCOE stands for Levelized Cost of Energy (here: renewable electricity supply)

Table 9
External costs associated with the environment (€c/kW h).

Technology	Ext_{min}	Ext_{max}	**Technology**	Ext_{min}	Ext_{max}
Wind (onshore)	0.017	0.083	Biomass	0.030	0.750
Wind (offshore)[a]	0.017	0.083	Natural gas	0.800	3.200
Nuclear	0.036	0.126	CHP[b]	0.890	5.275
Solar PV	0.162	0.162	Piston engine	1.650	6.050
Solar thermal[a]	0.162	0.162	Coal	0.980	7.350
Hydro (large)	0.010	0.330	Geothermal[c]	–	–
Hydro (small)[a]	0.010	0.330	Fuel cell[d]	–	–

Table 10
External costs associated with health (€c/kW h).

Technology	Ext_{min}	Ext_{max}	**Technology**	Ext_{min}	Ext_{max}
Wind (onshore)	0.034	0.168	Natural gas	0.200	0.800
Wind (offshore)[a]	0.034	0.168	CHP[b]	0.610	4.225
Solar PV	0.438	0.438	Biomass	0.170	4.250
Solar thermal[a]	0.438	0.438	Piston engine	1.350	4.950
Nuclear	0.164	0.574	Coal	1.020	7.650
Hydro (large)	0.020	0.670	Geothermal[c]	–	–
Hydro (small)[a]	0.020	0.670	Fuel cell[d]	–	–

Table 11
Number of employees per unit of electricity produced (job-years/GW h).

Technology	Values	Technology	Values
Solar PV	0.87	Wind (offshore)	0.17
Hydro (large)	0.55	Nuclear	0.14
Hydro (small)	0.27	Natural gas	0.11
Geothermal	0.25	Coal	0.11
Solar thermal	0.23	CHP[a]	0.11
Biomass	0.21	Piston engine[b]	–
Wind (onshore)	0.17	Fuel cell[b]	–

Table 13
Social acceptability levels.

Technology	Euro-barometer	Greenberg	Ipsos	Values
Solar PV	High	High	High	High
Solar thermal[a]	High	High	High	High
Wind (onshore)	High	High	High	High
Wind (offshore)[a]	High	High	High	High
Hydro (large)	High	High	High	High
Hydro (small)[a]	High	High	High	High
Geothermal	–	–	–	Medium
Biomass	Medium	–	–[b]	Medium
Natural gas	Medium	Medium	Medium	Medium
CHP[c]	Low	Low	Low	Low
Piston engine	Low	Low	Low	Low
Coal	Low	Low	Low	Low
Nuclear	Low	Low	Low	Low
Fuel cell[d]	–	–	–	–

Source: Maxim, A.: Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis. Energy Policy 65 (2014), pp. 284–297