TECHNISCHE UNIVERSITÄT WIEN
Vienna | Austria

Energy Economics Group

Measuring sustainable development in energy communities: Policy implications for sustainable and optimized community behavior

Matthias Maldet
Georg Lettner
Daniel Schwabeneder
Christoph Loschan

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- Introduction
- How to measure sustainable development?
- Case study: Community indicator application
- Case study: Results
- Alternative policy: Penalties and incentive schemes
- Summary and conclusions

Introduction

- Energy system transition in regard with sustainable development
- Consider resource utilization in the energy system
- United Nations Sustainable Development Goals (UN SDG)
- Established 17 goals
- 169 potential actions to achieve these goals
- Social and environmental improvements

https://sdgs.un.org/goals

Introduction

- Energy and resource related SDG
- SDG 6, 7, 12, 13

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- Consider cost load on consumers in energy transition and sustainable development
- SDG1

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Introduction

- Energy and resource related SDG
- SDG 6, 7, 12, 13
- Consider cost load on consumers in energy transition and sustainable development
- SDG1
- Transition to sustainable cities and communities
- SDG11

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Introduction

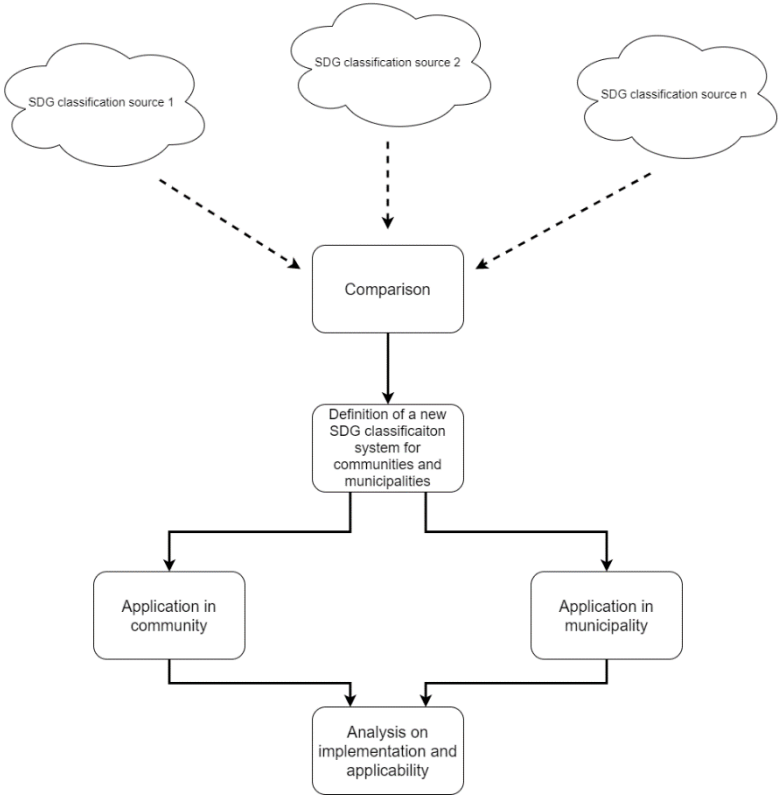
- Energy and resource related SDG
- SDG 6, 7, 12, 13
- Consider cost load on consumers in energy transition and sustainable development
- SDG1
- Transition to sustainable cities and communities
- SDG11
- This work focuses on these six UN SDG

https://sdgs.un.org/goals

How to measure local sustainable development?

- Contribution of energy system operations to the UN SDG must be measured
- UN with 169 potential indicators
  - High complexity and adaptation to local context required
  - Source: United Nations, "Transforming our world: the 2030 Agenda for Sustainable Development," Online; accessed 13 February 2023. [Online]. Available: https://sdgs.un.org/2030agenda
- ISO 37120 as norm for sustainable communities
  - Indicators, but not directly in regard with UN SDG
  - Source: ISO, ISO 37120:2018: Sustainable cities and communities — Indicators for city services and quality of life. ISO, 7 2018.
- OECD indicators
  - Nationally applicable indicators but not in local context
  - Source: OECD, "Measuring distance to the SDG targets," 6 2017. [Online]. Available: https://www.oecd.org/sdd/OECD-Measuring-Distance-to-SDG-Targets.pdf
- Paper from Jossin and Peters with municipal UN SDG indicators
  - Large sets of indicators and thus complex
  - Source: J. Jossin and O. Peters, "Sustainable Development Goals (SDG) indicators for municipalities: a comprehensive monitoring approach from Germany," Journal of Urban Ecology, vol. 8, p. juac020, 1 2022. [Online]. Available: https://doi.org/10.1093/jue/juac020
- High complexity and requirement of adaption to local conditions→ Development of an own indicator system and application in a community

How to measure local sustainable development?



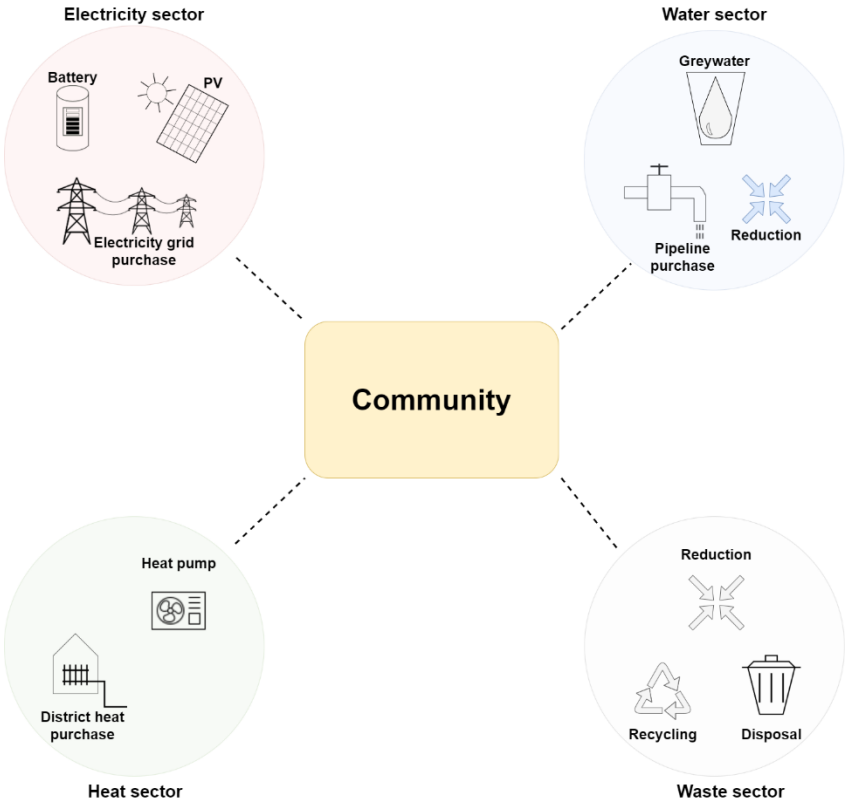
How to measure local sustainable development?

SDG	Community indicator
1: No poverty	Community cost reduction compared to BaU in % (Equation 1)
6: Clean water and sanitation	Percentage of reduced water and reused greywater in relation to community water demand (Equation 2)
7: Affordable and clean energy	Community share of renewable energy generation in % (Equation 3)
11: Sustainable cities and communities	Combination impact of other SDGs in communities
12: Responsible consumption and production	Community share of reduced and recycled waste to accruing waste (Equation 4)
13: Climate action	Community emission reduction compared to BaU in % (Equation 5)

- $Eq1: i^{SDG1} = \frac{c^{tot,BaU} - c^{tot}}{c^{tot,BaU}}$
- $Eq2: i^{SDG6} = \frac{v_{water}^{reduced} + v_{water}^{greywater}}{D_{water}}$
- $Eq3: i^{SDG7} = \frac{q^{ren}}{q^{tot}}$
- $Eq4: i^{SDG12} = \frac{m_{waste}^{recycled} + m_{waste}^{reduced}}{M_{waste}^{total}}$
- $Eq5: {}^{SDG13} = \frac{em^{tot,BaU} - em^{tot}}{em^{tot,BaU}}$

Case study: Community indicator application

- Community GeWoZu in Waidhofen/Ybbs (Lower Austria)
- Simulation with linear optimization model (LP)
- Cost minimization
- Investment in technologies to achieve sustainable development
- Model performs investment decisions
- Sectors: electricity, heat, waste and water
- Aggregation of consumers
- Application of proposed indicators

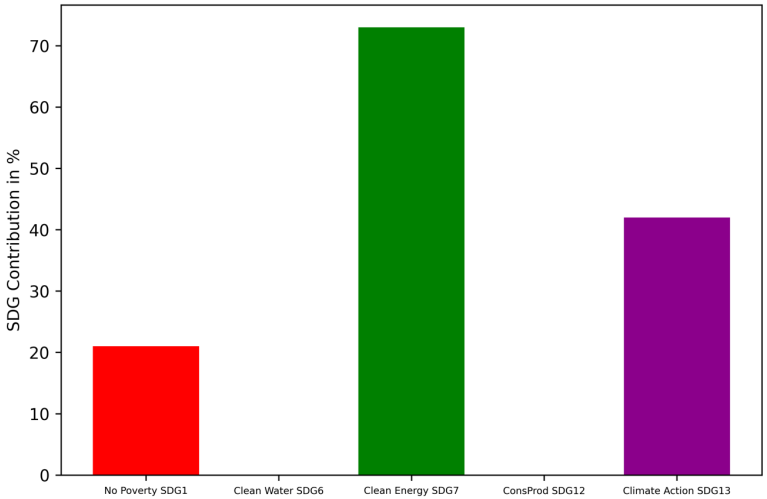


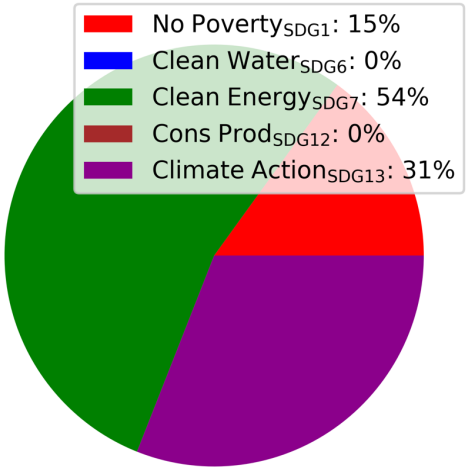
Case study: Community indicator application

- Application of proposed indicators
- Particular indicator contributions as constraints in the model
  - $i^{SDG} \geq I_{min}^{SDG}$
- Dual variables of constraints to determine costs for target achievement
  - $i^{SDG} - I_{min}^{SDG} \geq 0 : \lambda^{SDG}$
- Sensitivity analyses on minimum targets
  - $I_{min}^{SDG} \in [I_{min,low}^{SDG}, I_{min,high}^{SDG}]$
- Determine costs and limits for indicators
- At $I_{min,high}^{SDG}$: model infeasible

Case study: Results – No particular targets

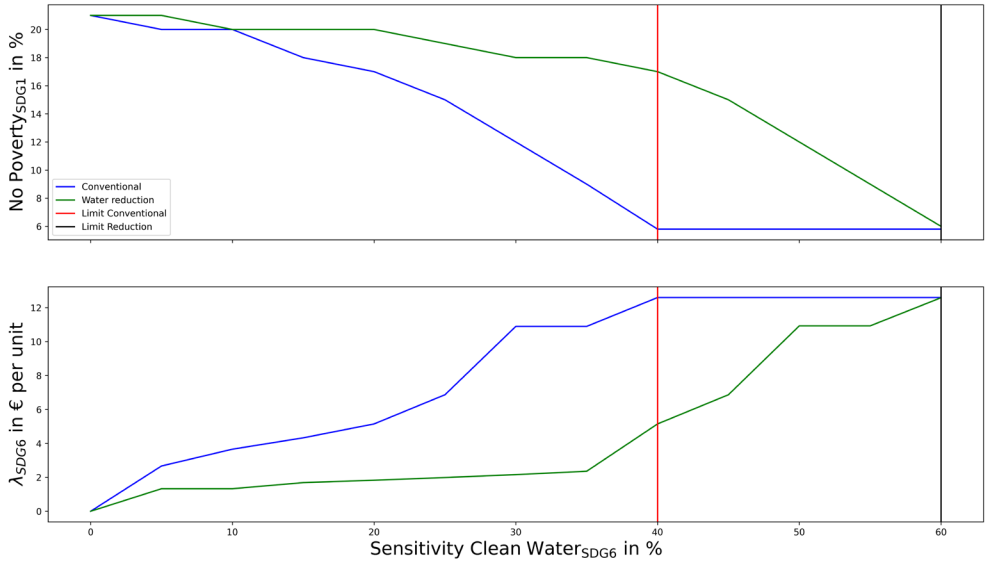
- Investments without particular targets lead to 21% cost reduction (market driven)
- SDG6 (clean water and sanitation) and SDG 12 (responsible consumption and production) not targeted without constraints
- SDG7 (clean and affordable energy): 73%
- SDG13 (climate action): 42%





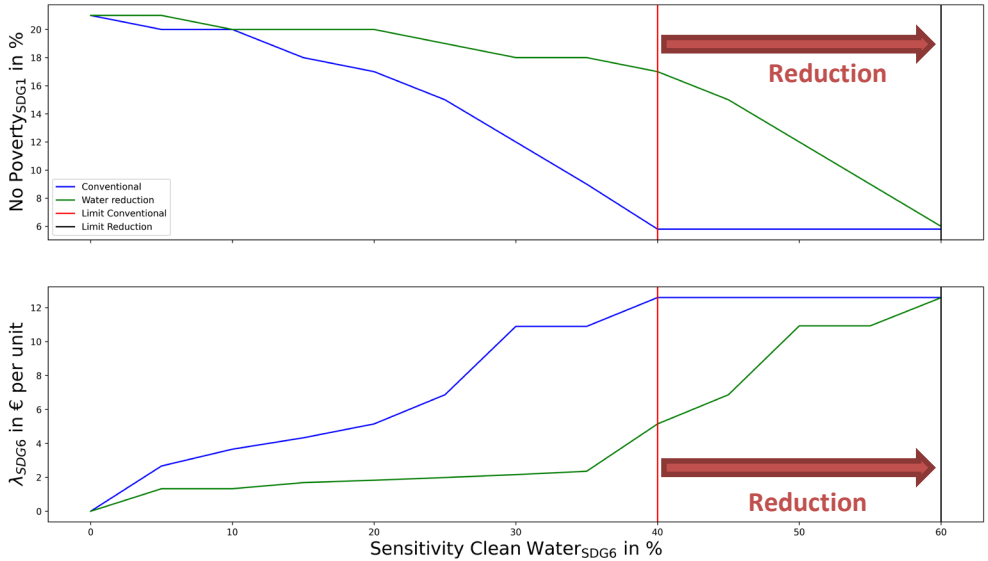
Case study: Results – SDG6 sensitivity

- SDG6 contribution by greywater system installation
- Leads to high costs
- SDG6 limit at 40% (not all water can be provided by greywater)



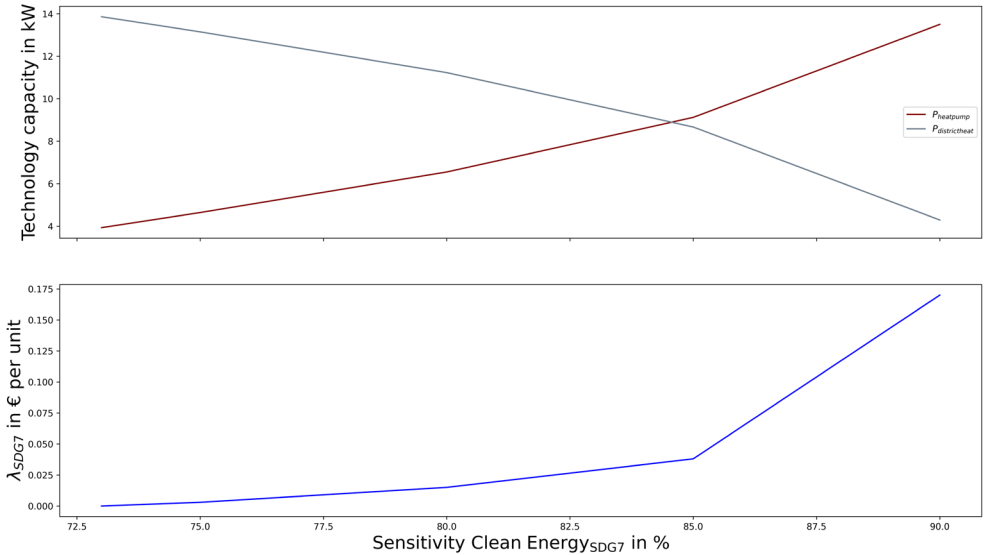
Case study: Results – SDG6 sensitivity

- SDG6 contribution by greywater system installation
- Leads to high costs
- SDG6 limit at 40% (not all water can be provided by greywater)
- Cost reduction and target extension to 60% by water reduction



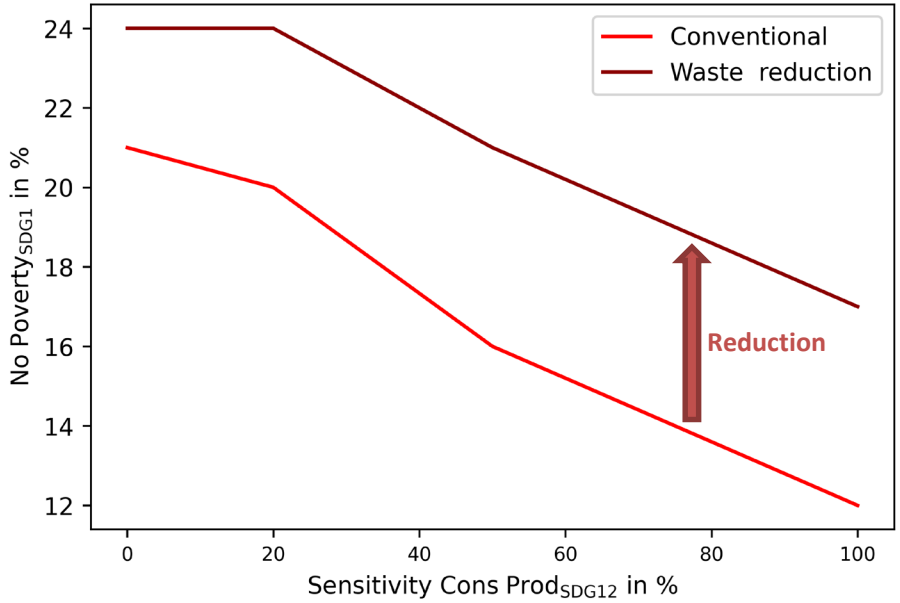
Case study: Results – SDG7 sensitivity

- Increasing heat pump installation in favour of district heat connection → Electrification
- Contributions up to 90%
- Costs for achievement low compared to SDG6
- High targets over 85% with sharp cost increase



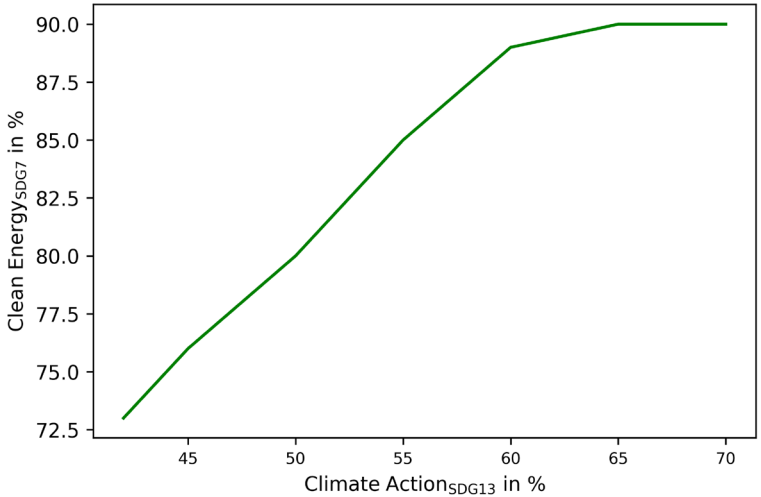
Case study: Results – SDG12 sensitivity

- Higher targets → recycling instead of dumping
- Additional recycling leads to cost increases
- Recycling must be promoted by market prices for secondary materials
- Cost reduction with higher waste reduction



Case study: Results – SDG13 sensitivity

- Direct correlation between SDG7 and SDG13 (climate action)
- Energy-system related emission reductions
- At SDG13 over 60%, SDG7 only slightly increases
- Additional actions taken for emission reductions
- Resource-related emission reduction such as greywater installation and recycling



Case study: Results – Simultaneous sensitivity

- Active targets
  - SDG targets active at different limits (KKT: dual variables unequal to zero)
  - SDG6 and SDG12 active at 5% → immediate actions required
  - SDG13 at 50%
  - Correlation SDG7 and SDG13 → SDG7 automatically targeted
  - Constraint becomes active at 90%
- Limits
  - Similar to single SDG targets
  - SDG6 limit at 40%, followed by SDG13 at 70% and SDG7 at 90%
  - No recycling limit assumed → no SDG12 limit

Case study: Results – Simultaneous sensitivity

- Higher targets: heat pump installation increases in favour of district heat
- Greywater installation for SDG6
- Limit at 40%
- PV and battery only slightly affected

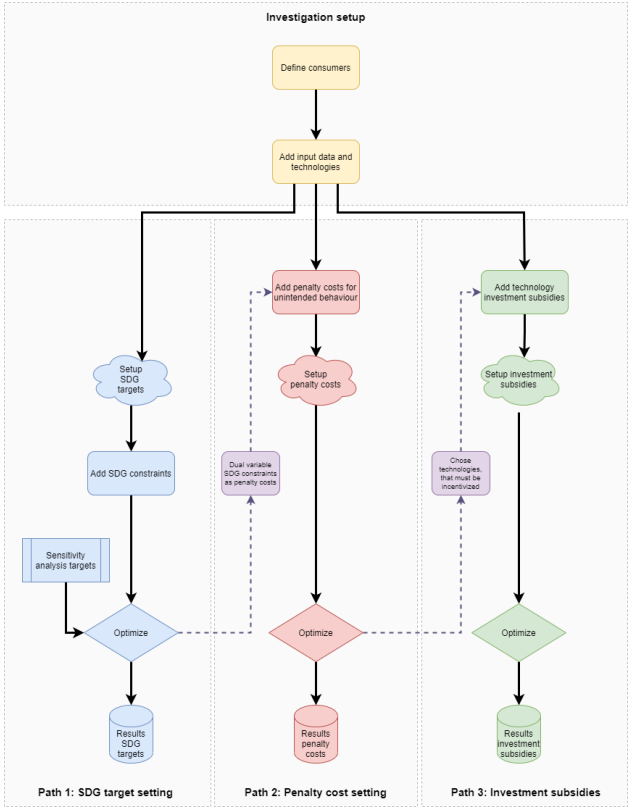
Sens. in %	PV in kWp	Battery in kWh	Heat pump in kW	District heat in kW	Grey water systems in l
0	30.00	3.65	3.93	13.86	0
5	30.00	3.65	3.93	13.86	8
45	30.00	3.65	3.93	13.86	150
50	30.00	3.65	4.69	13.10	150
70	30.00	3.95	14.47	3.32	150
90	29.86	3.98	14.21	3.58	150
100	30.00	4.00	14.97	2.80	150

- Costs increase with higher target achievement
- At 45%, costs higher than without technology installation
- Cost increases for sustainable development must be covered
- Incentive schemes required

Sens. in %	SDG1	SDG6	SDG7	SDG12	SDG13
0	21	0	73	0	42
5	20	5	73	5	42
45	-4	45	73	45	47
50	-5	45	75	50	50
70	-10	45	90	88	70
90	-11	45	90	90	70
100	-11	45	90	100	70

Alternative policy: Penalties and incentive schemes

- Three intertwining Policy paths
- Policy path 1: Target setting
  - Strict SDG targets
  - Previously presented results
- Policy path 2: Penalty charging
  - Penalties for non-sustainable behaviour
  - Derived from dual variables from Policy path 1
- Policy path 3: Investment subsidies
  - Investment subsidies in clean technology
  - Identified in Policy path 2
- Analysis and comparison of paths



Alternative policy: Penalties and incentive schemes

- Investigation cost efficiency of incentive scheme
- SDG6: Greywater installation
- SDG7: District heat penalties
- SDG12: Waste disposal penalty
- Only investment subsidies with lower incentive costs
  - SDG6 as dominant factor
  - High greywater installation costs
- Combination of penalties and subsidies with highest cost efficiency
- Incentive scheme setting depends on particular SDG

Policy	Incentive	Incentive costs in €	Total community costs in €	Cost increase in %
No incentives	-	0	18723	0
Sewage disposal penalty	10.9 €/m^3	10064	20701	10.57
Greywater incentive	400 €/l	2020	20464	9.30
District heat procurement penalty	0.038 €/kWh	194	18979	1.37
Heat pump subsidies	400 €/kW	506	18875	0.81
Waste disposal penalties	0.15 €/kg	0	20895	11.60
Waste recycling subsidies	0.15 €/kg	2228	20895	11.60
CO_2 price	1.17 €/kg$_{CO2}$	8001	20413	9.02
CO_2 price	0.07 €/kg$_{CO2}$	697	18771	0.26
Combination penalties	-	10650	23184	23.83
Combination subsidies	-	5311	23811	27.17
Combination half subsidies, half penalties	-	3011	23161	23.70

Summary and conclusions

- SDG6 (clean water and sanitation) and SDG12 (responsible consumption and production) not targeted without constraints
- Market interventions required
- SDG targets lead to cost increases → Costs depend on SDG
- Resource demand reduction can help lowering the costs
- However, for sustainable development, incentives for consumers‘ cost reductions are crucial
- Policy actions in the form of incentive schemes or penalties as alternative
- Incentive depend on particular SDG

Acknowledgement

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TECHNISCHE UNIVERSITÄT WIEN
Vienna | Austria

Energy Economics Group

Matthias Maldet

Technical University of Vienna
Institute of Energy Systems and Electrical Drives
Energy Economics Group - EEG

Gußhausstraße 25-29 / E370-3
1040 Vienna, Austria

(T) +43 1 58801 370 365
(E) maldet@eeg.tuwien.ac.at
(W) www.eeg.tuwien.ac.at