ENERGY SUPPLY, ECONOMICS AND TRANSITION

ENV-410
Energy supply, economics and transition: Behavioral perspective on the diffusion of innovations

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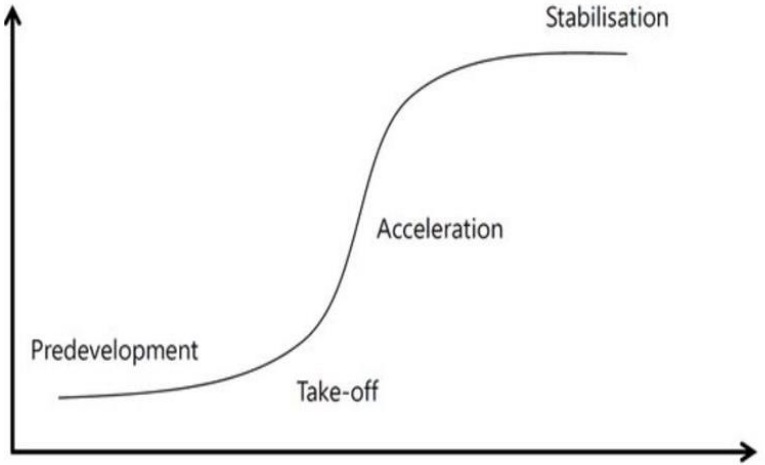
Laboratory for Human-Environment Relations in Urban Systems

April 30, 2025

Christophe Ballif / Philippe Thalmann / Claudia Binder

Recap: Socio-technical perspective of energy transitions

- Key phases of transitions



Rotmans et al., 2001

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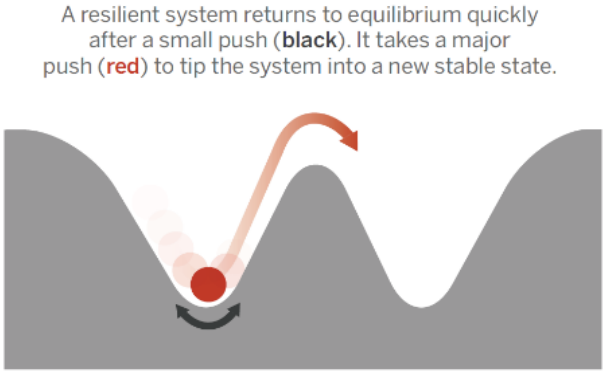
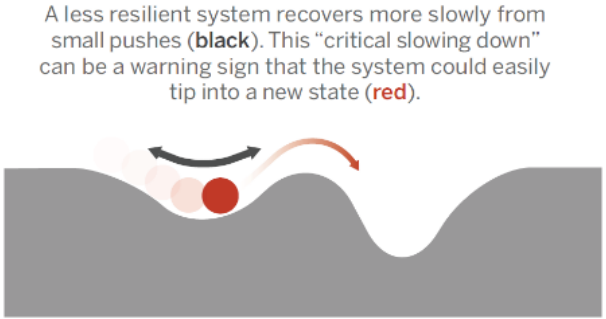
Recap: Socio-technical perspective of energy transitions

- Key phases of transitions
- Tipping point concept





Scheffer et al. 2009; Popkin 2014

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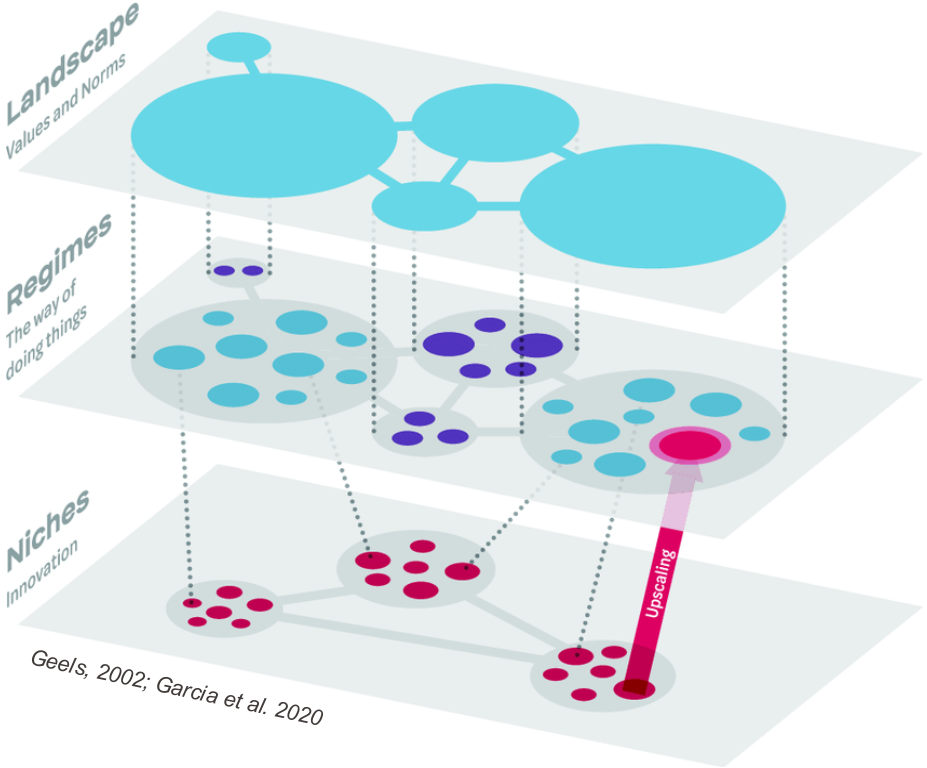
Recap: Socio-technical perspective of energy transitions

- Key phases of transitions
- Tipping point concept
- Multi-level perspective to study socio-technical systems



Geels, 2002; Garcia et al. 2020

Energy transition perspectives

Socio-technical perspective of the energy transition
Multi-level perspective and social tipping points
Claudia R. Binder

Behavioral perspective
Diffusion of innovations and the role of proximity effects
Maria Anna Hecher and Glòria Serra Coch

Material perspective
Demand and supply materials of the energy transition
Francisco Xavier Felix Martin Del Campo

Actors' perspective
Complex actor network of the Swiss energy sector
Susan Mühlemeier

Goals

- Grasp the **concept of social acceptance** and its relevance in the energy transition.
- Explore **key theories** to understand the adoption and diffusion of innovations.
- Learn about the **characteristics of (potential) adopters** and their **drivers and barriers** to inform policy design.
- Learn how to **integrate human behavior** into energy models.

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Social acceptance of renewable energy technologies

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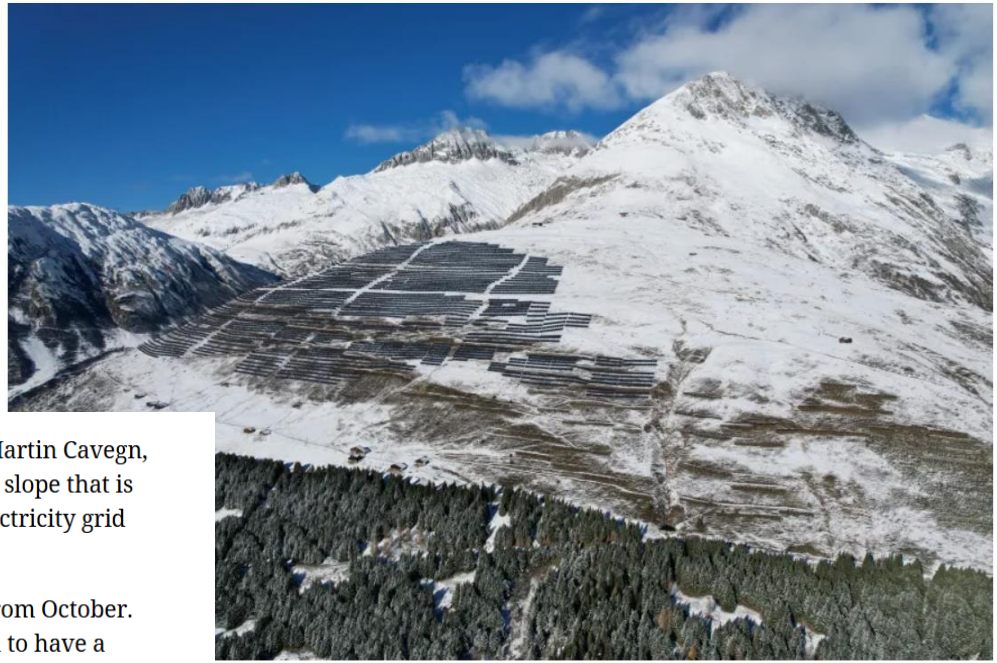
First large-scale solar park in Swiss Alps



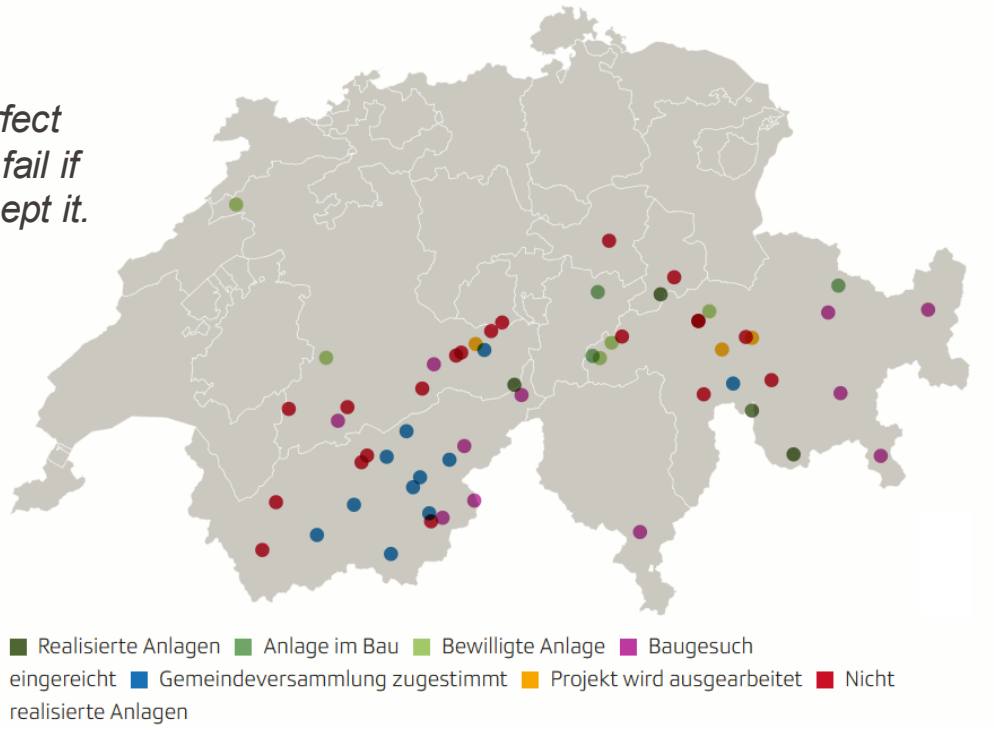
Swissinfo, Sept 2024

"It's a once-in-a-lifetime project," the local mayor, Martin Cavegn, told Swiss public television, SRF. "It's a south-facing slope that is fully developed. There are already roads and an electricity grid connection. It is very easy to build here."

The first new panels for the park will be installed from October. When completed, the 300,000m2 facility is expected to have a capacity of 19.3 megawatts – almost ten times the amount produced by the largest existing solar plant in the Swiss Alps, on the Muttsee dam. The Sedrun facility should cover the needs of 6,500 local homes.

Alpine PV plants in Switzerland

A technically perfect solution can still fail if people don't accept it.



SRF, Feb 2024

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Why does social acceptance matter in the energy transition?

- Technological feasibility doesn't guarantee successful implementation - public acceptance is crucial.
- Despite high general support for renewables, specific projects often face local opposition.
- Understanding social acceptance is essential for the diffusion of renewable energy technologies.

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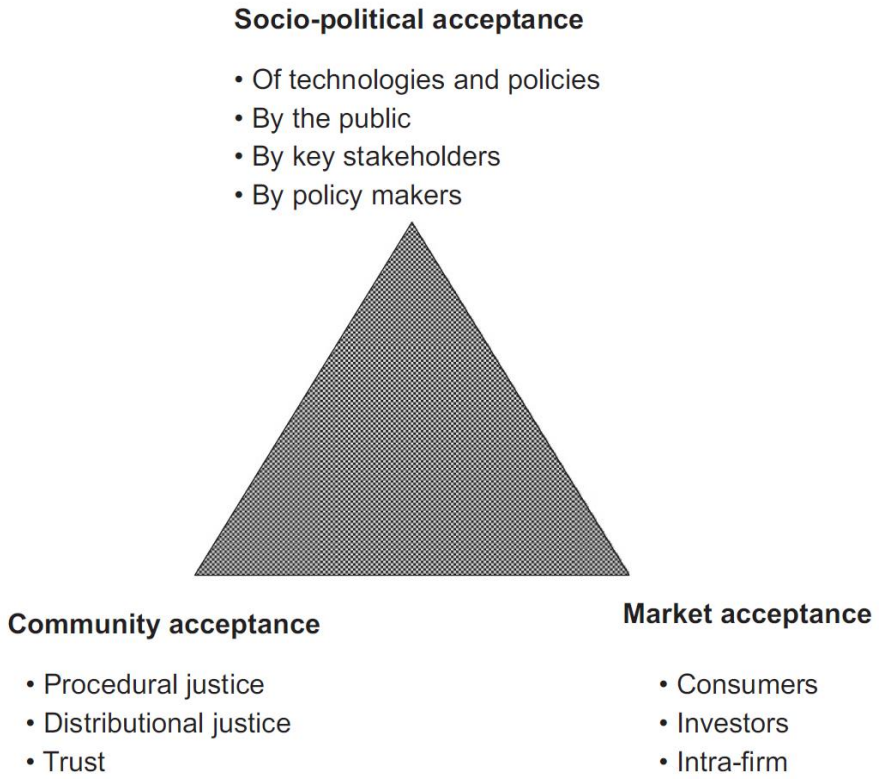
Three dimensions of social acceptance

- **Social-political acceptance** (global level)
- **Community acceptance** (fairness and trust)
- **Market acceptance** (adoption of innovations, local level)



Wüstenhagen et al., 2007

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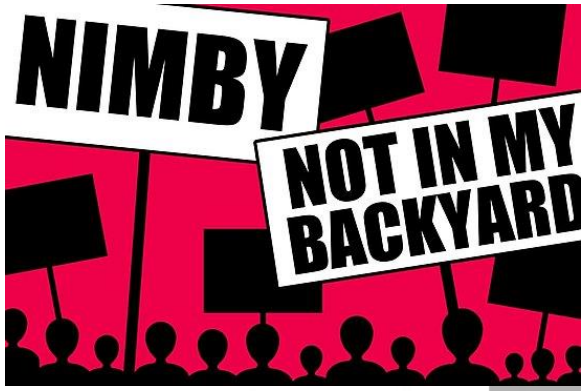
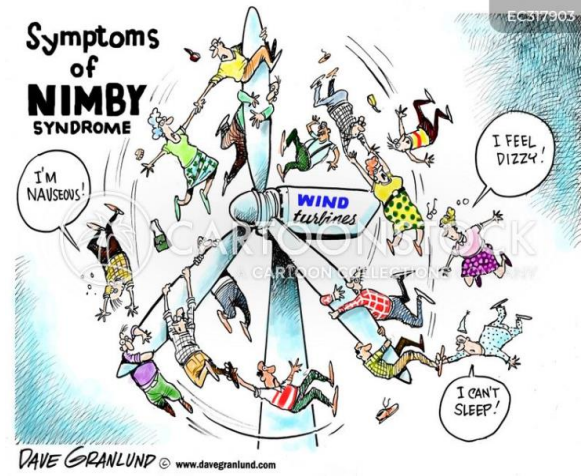
Challenges in achieving social acceptance

- **NIMBYism:** "Not In My Backyard" attitudes
- **Visual Impact:** Concerns over landscape changes
- **Trust Deficit:** Lack of trust in developers and authorities
- **Equity Concerns:** Perceived unfair distribution of costs and benefits





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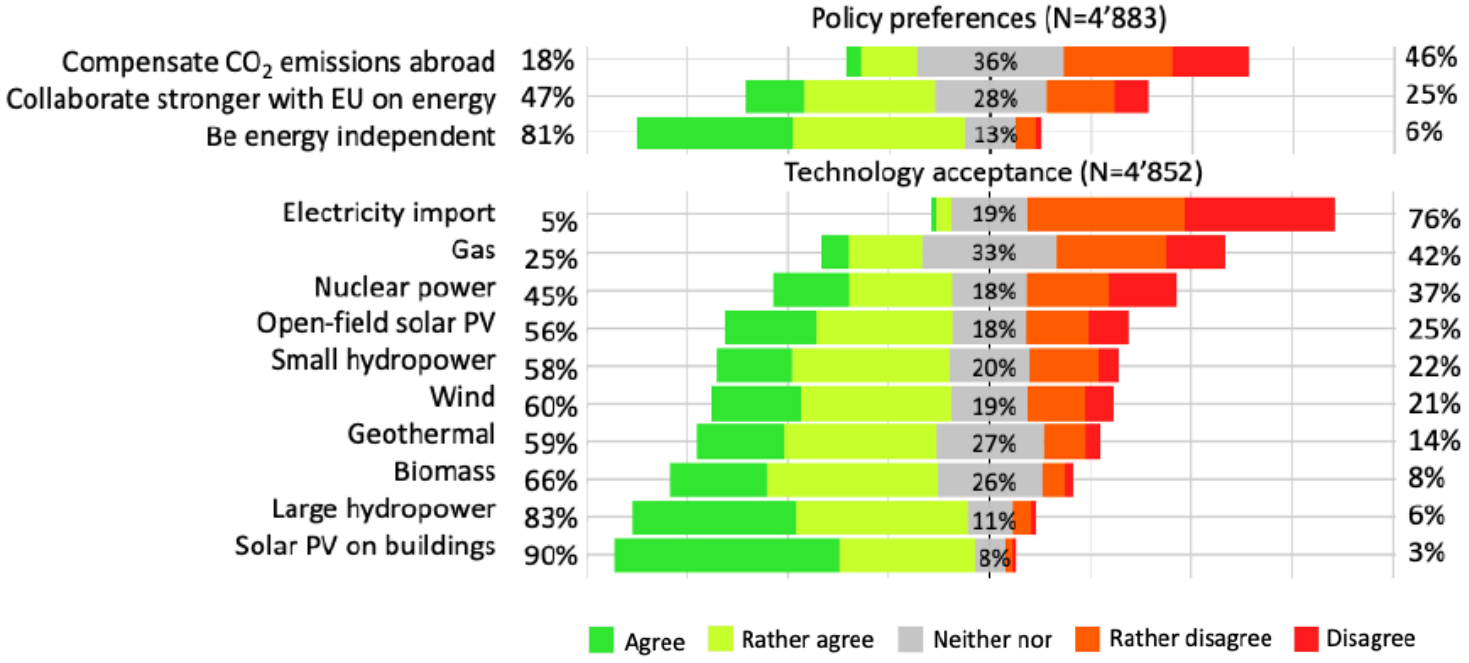
- In order to guarantee **Switzerland's electricity supply** in the future, ...

Mentimeter

Socio-political acceptance of energy technologies in Switzerland



Trutnevyte et al., 2024

Strategies to enhance social acceptance

- **Community engagement:** Involve local stakeholders early in the planning process.
- **Transparent communication:** Provide clear information about benefits and impacts.
- **Equitable benefit sharing:** Ensure fair distribution of economic and social benefits.

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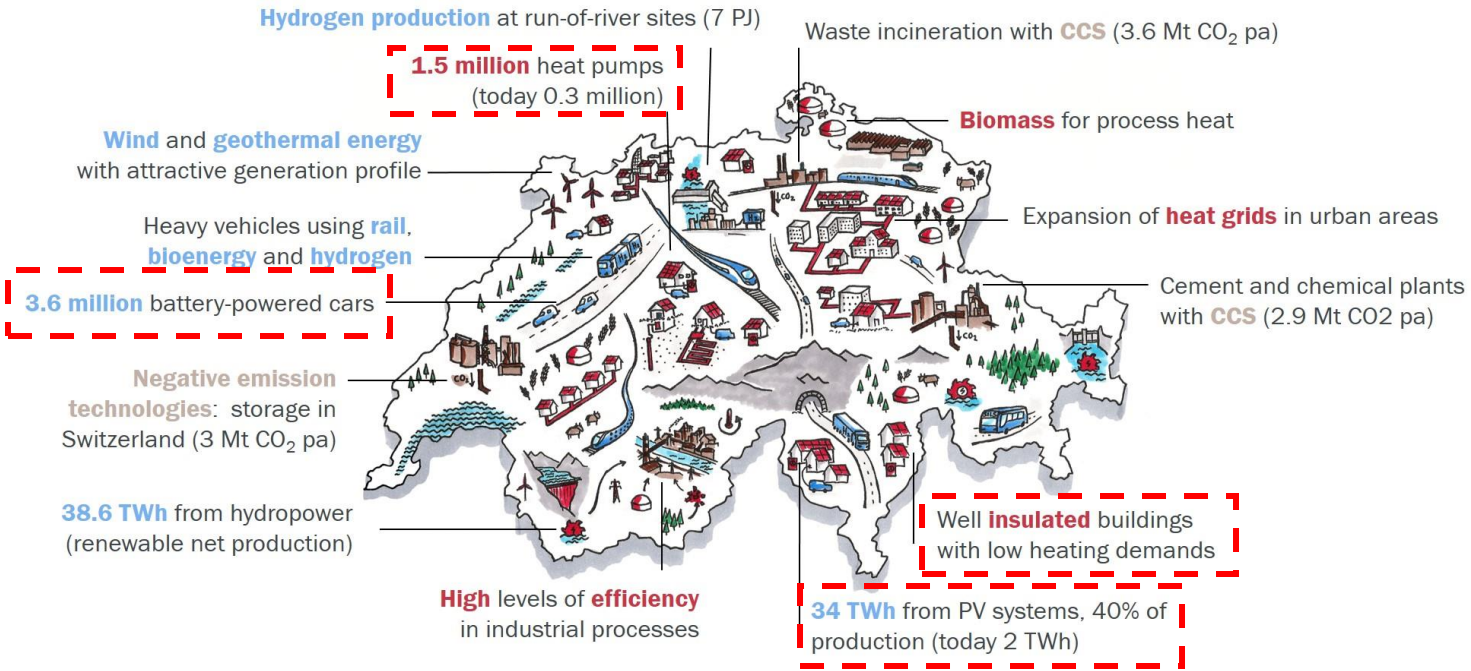
Adoption and diffusion of innovations

Renewable energy technologies in the Swiss residential building sector

Objectives for a climate-neutral Switzerland by 2050



SFOE, 2020

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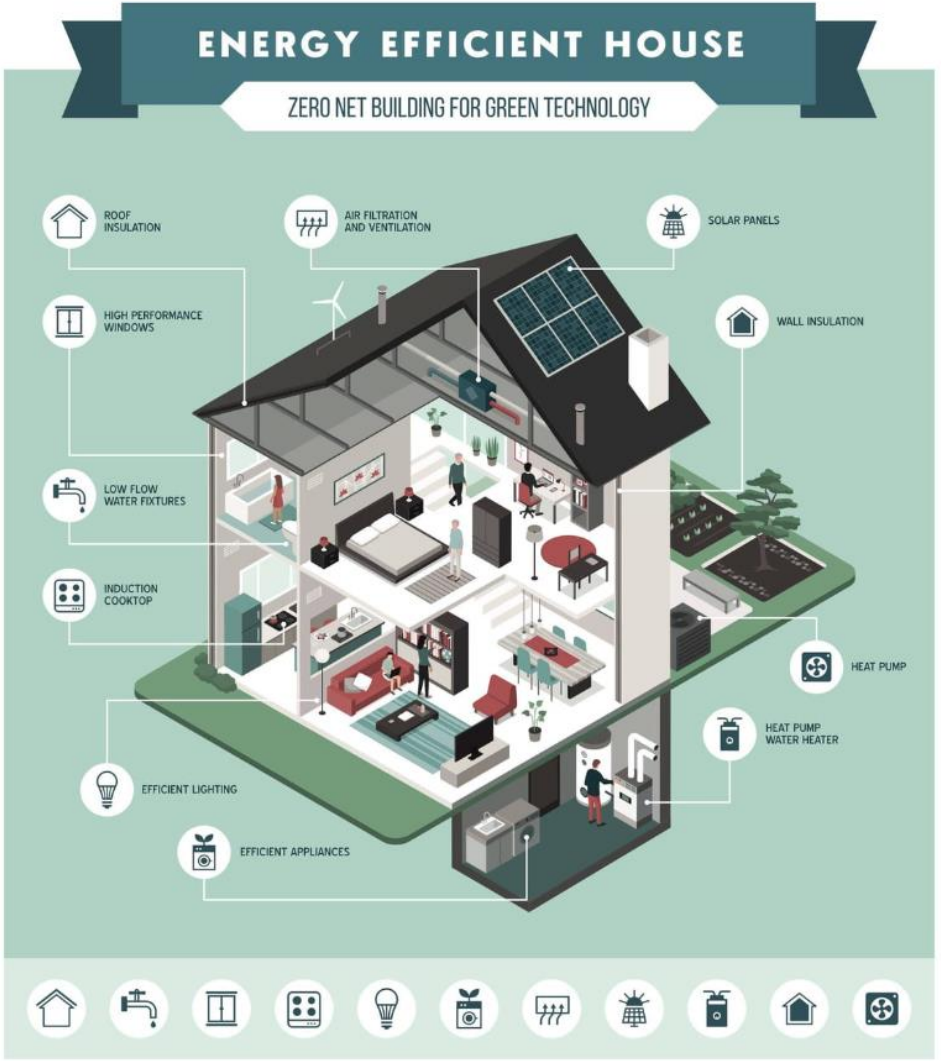
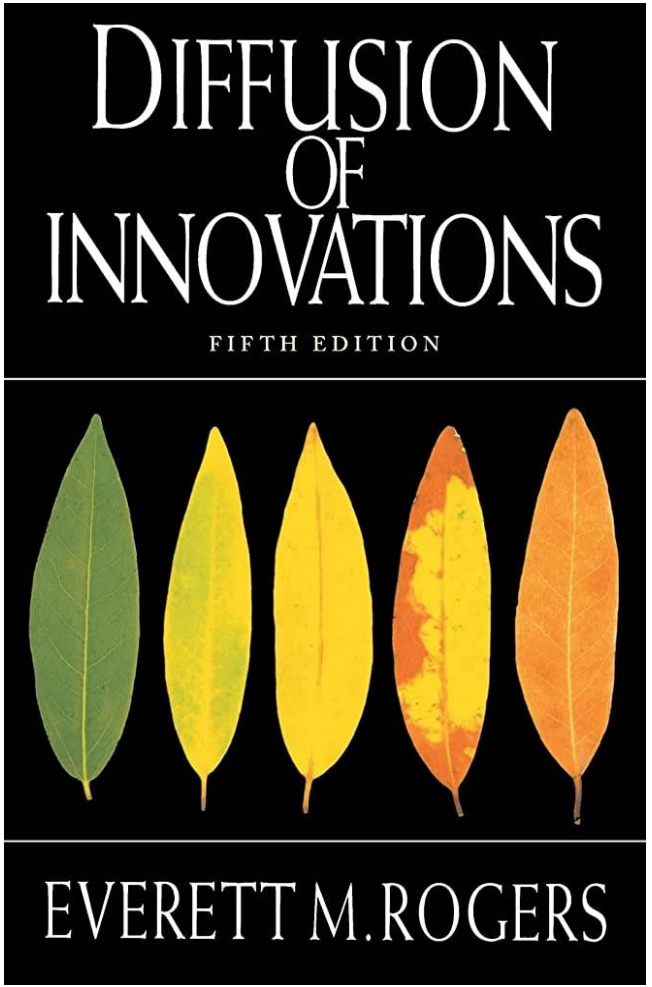
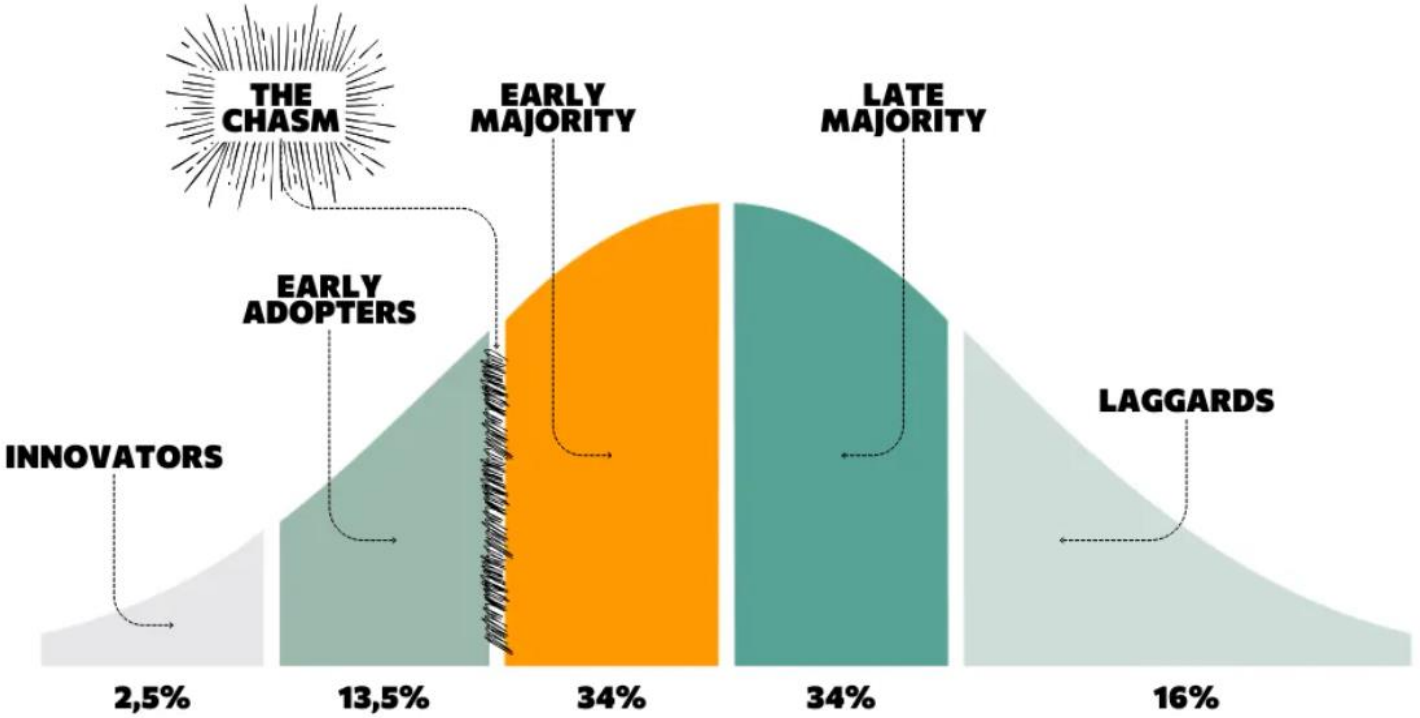
Renovations and energy technology adoption in residential buildings have long-term impacts



Rogers' Diffusion of Innovations Theory

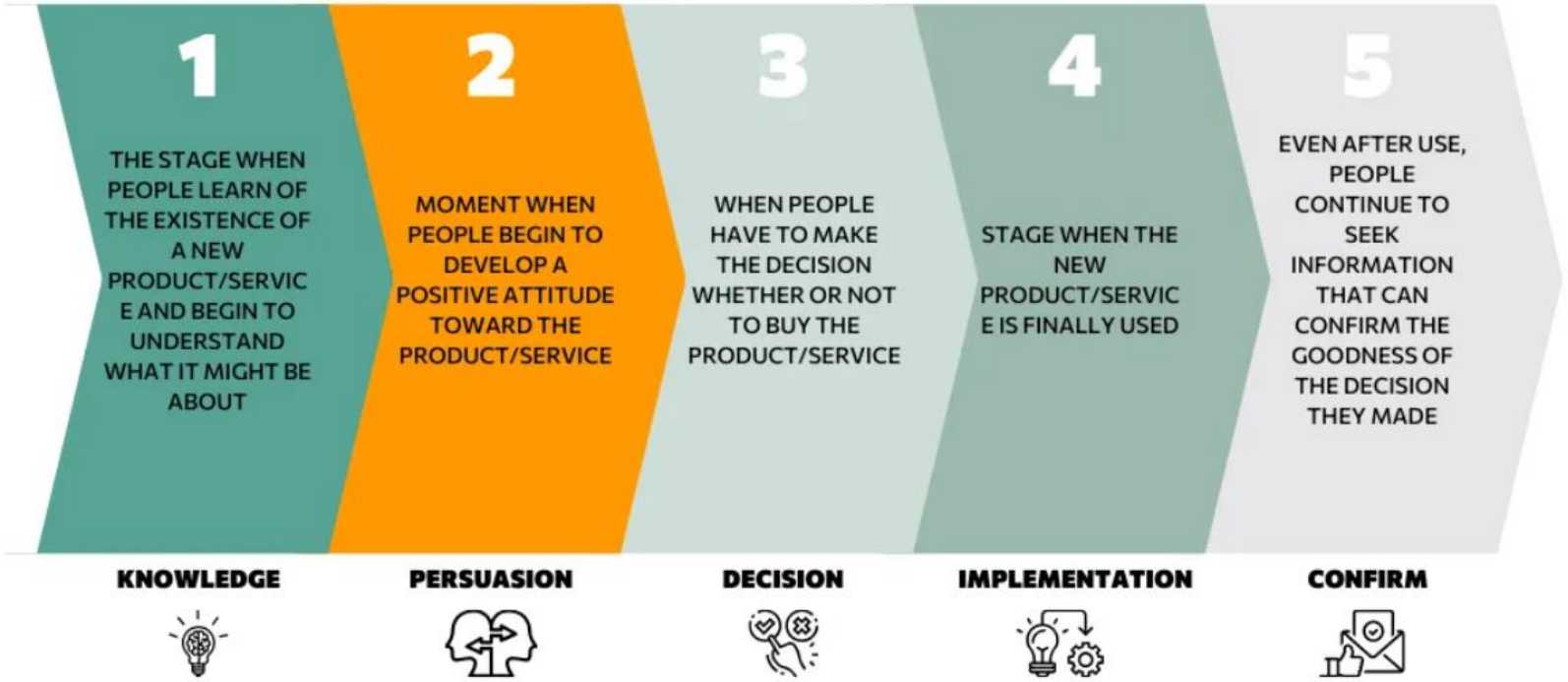


Rogers: Users of innovations



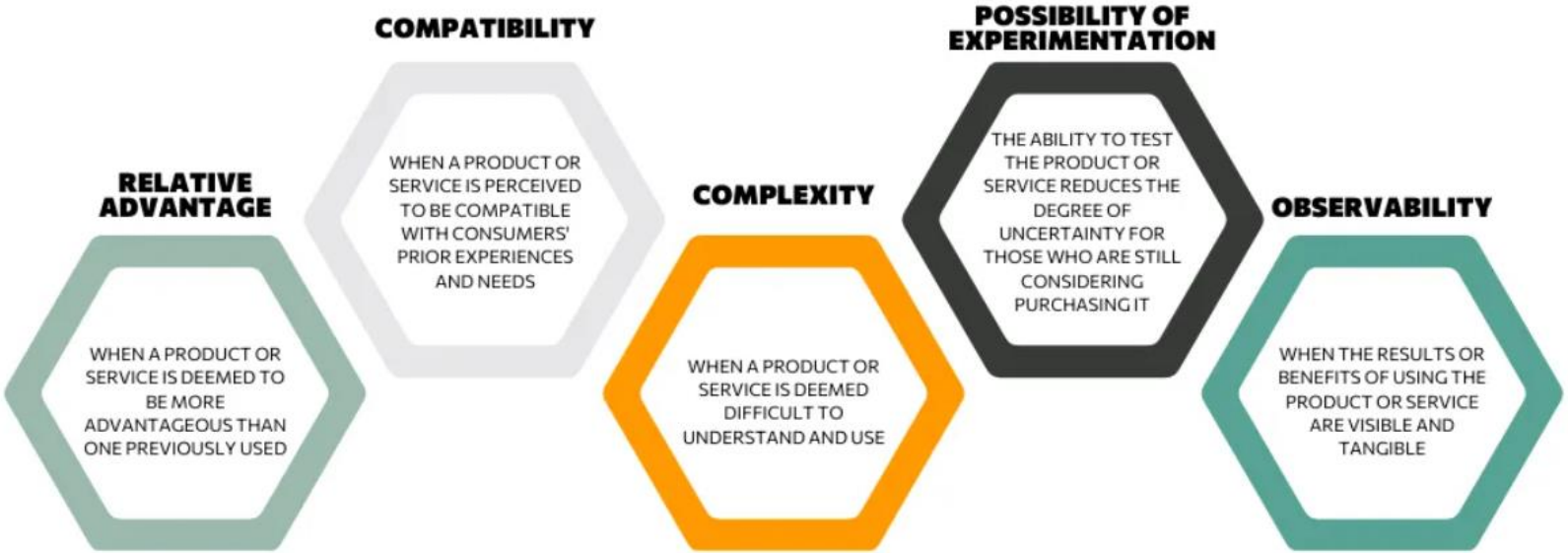
Rogers, 1962

Rogers: 5 stages of decision-making



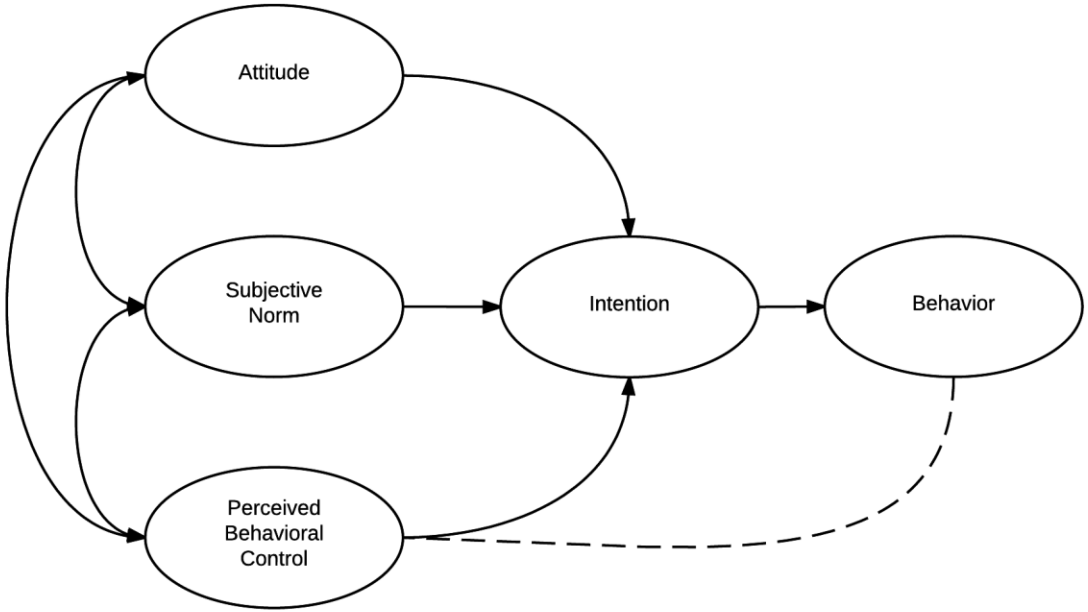
Rogers, 1962

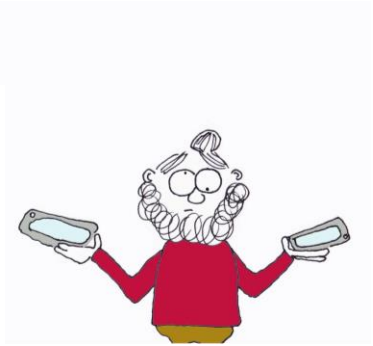
Rogers: Factors influencing decision-making



Rogers, 1962

Ajzens' Theory of Planned Behavior

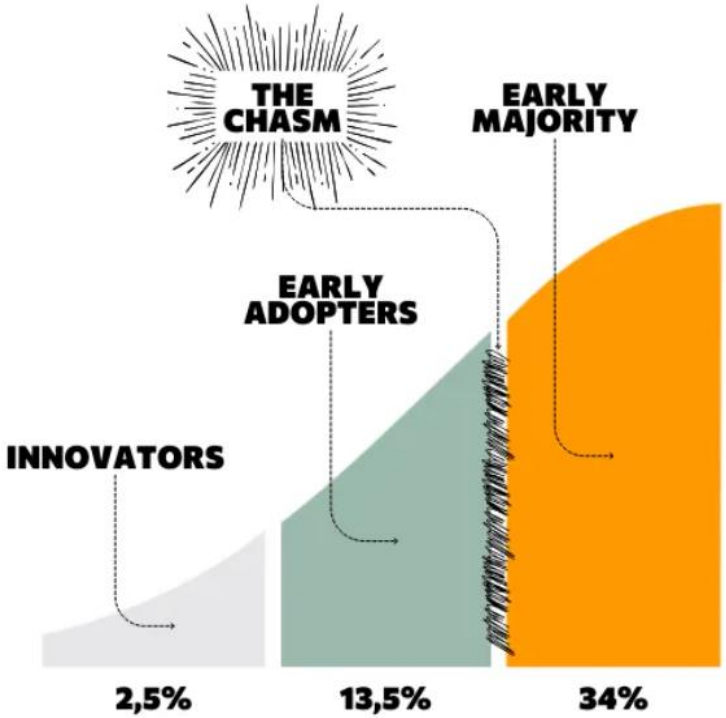




Video

Ajzen, 1985

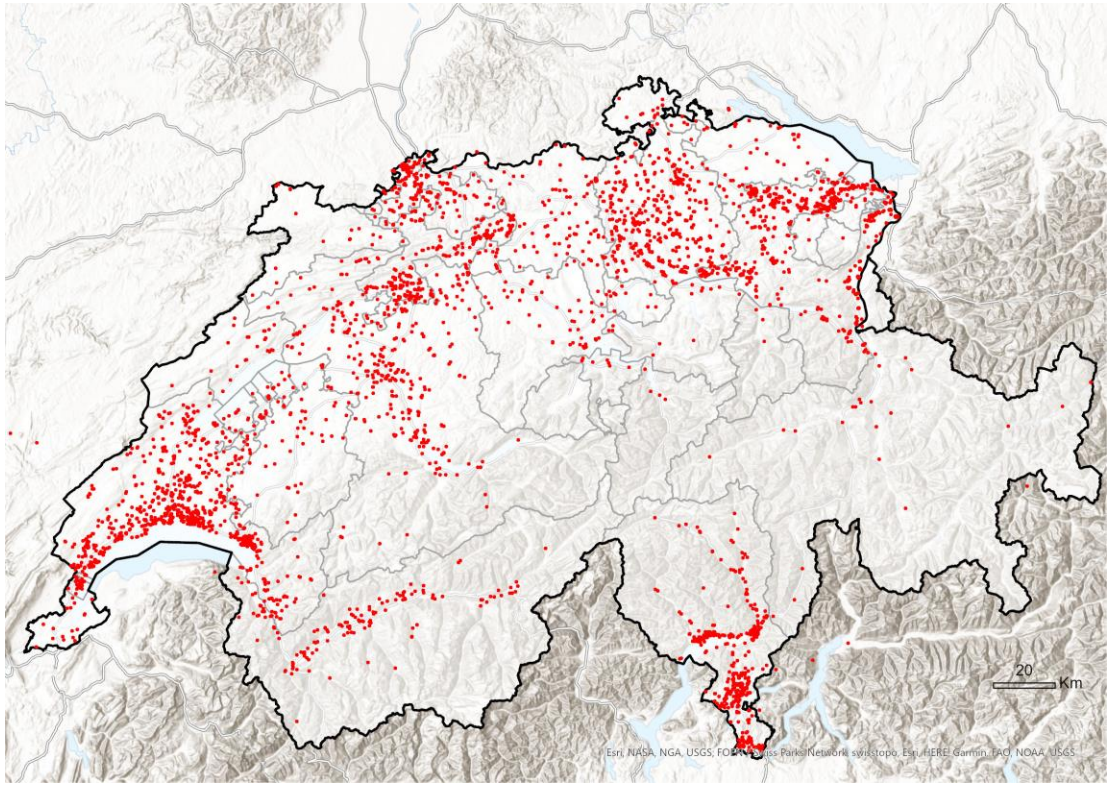
Technology adopter profiles



- What **characteristics** do you think technology adopters have?
- What do you think are the **drivers** for installing renewable energy technologies?

Mentimeter

4’850 Swiss households with PV or EV



German speaking part

SG/ST	ZH	…
25%	11%	11%

French speaking part

VD	BE/VS /FR	GE/JU /NE
25%	14%	2%

Italian speaking part

TI
12%

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Characteristics of technology adopters

	Survey respondents who have... EMS, PV and EV N=1076	only PV N=630	only EV N=800	Swiss population
Socio-demographics				
Mean age	56	61	50	43
Tertiary education level	47%	37%	51%	25%
Employed	74%	56%	82%	59%
Retired	22%	41%	15%	23%
Monthly household income > CHF 9000	61%	33%	56%	12%
Couple with children	61%	49%	48%	34%
Buildings				
Homeowners	98%	100%	62%	36%
Single-family building	82%	83%	44%	57%
Renovation with technology adoption	25%	24%	8%	-

HERUS, 2024; Hecher et al., 2025

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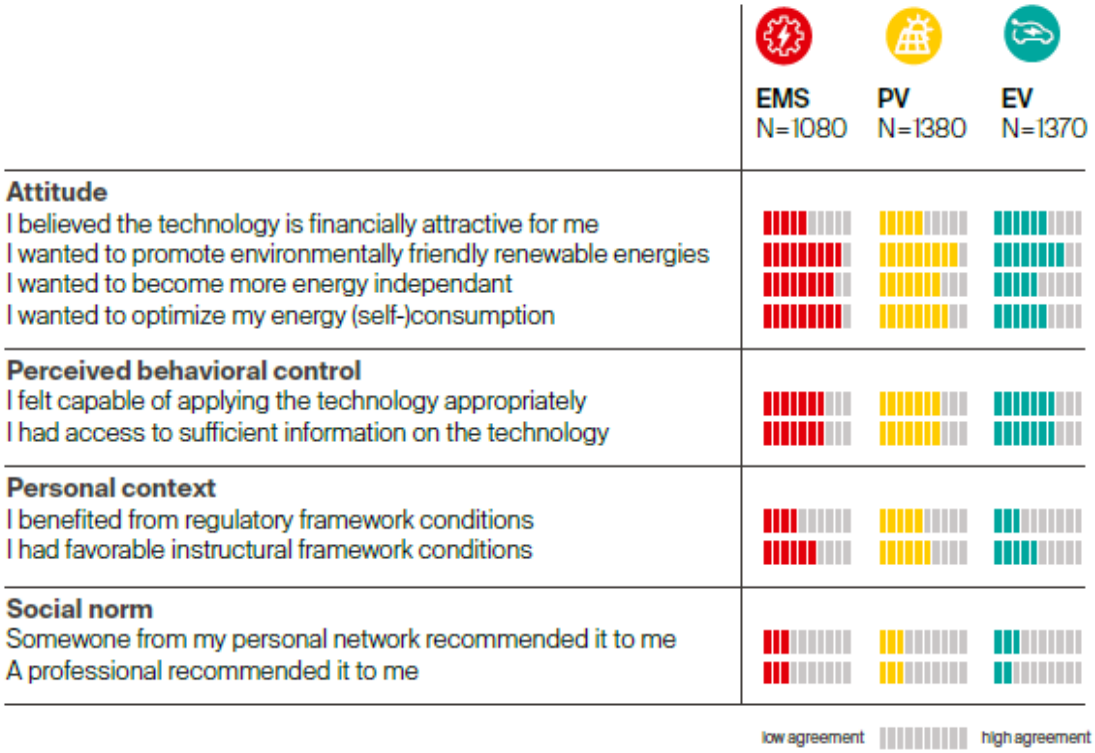
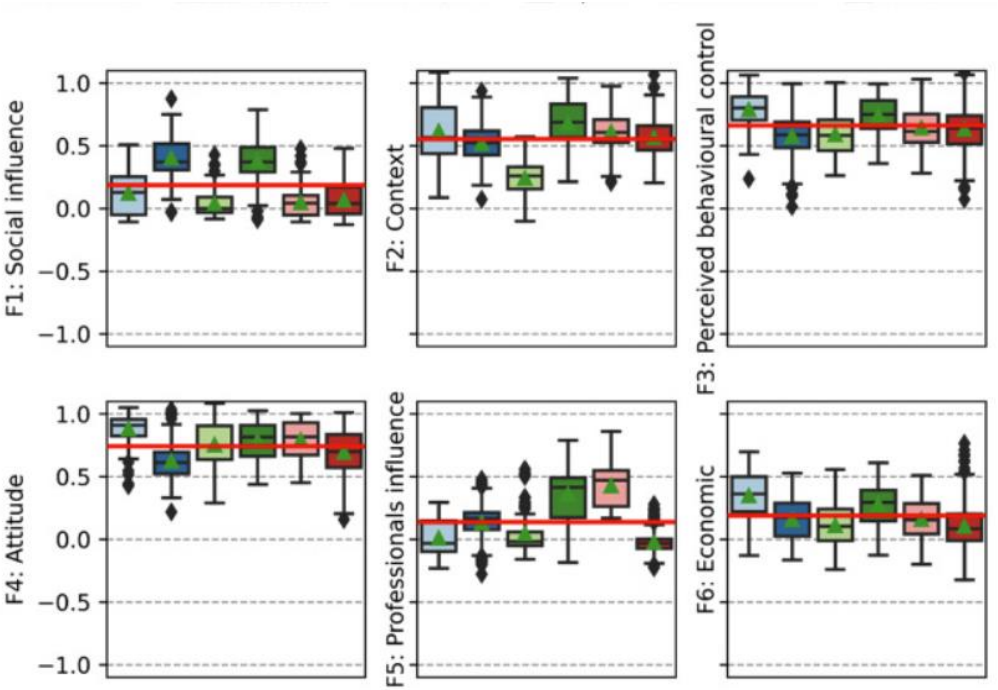
Drivers for energy technology adoption



HERUS, 2024; Hecher et al., 2025

Drivers for PV adoption: PV adopter clusters



Martinez et al., 2025

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Technology bundles

Innovation theory

*"… consists of one or more **distinguishable elements of technology** that are perceived as being closely interrelated."*

*"… determine the **degree of compatibility** perceived by individuals among interrelated ideas."*

Rogers, 1962: 226

Marketing research

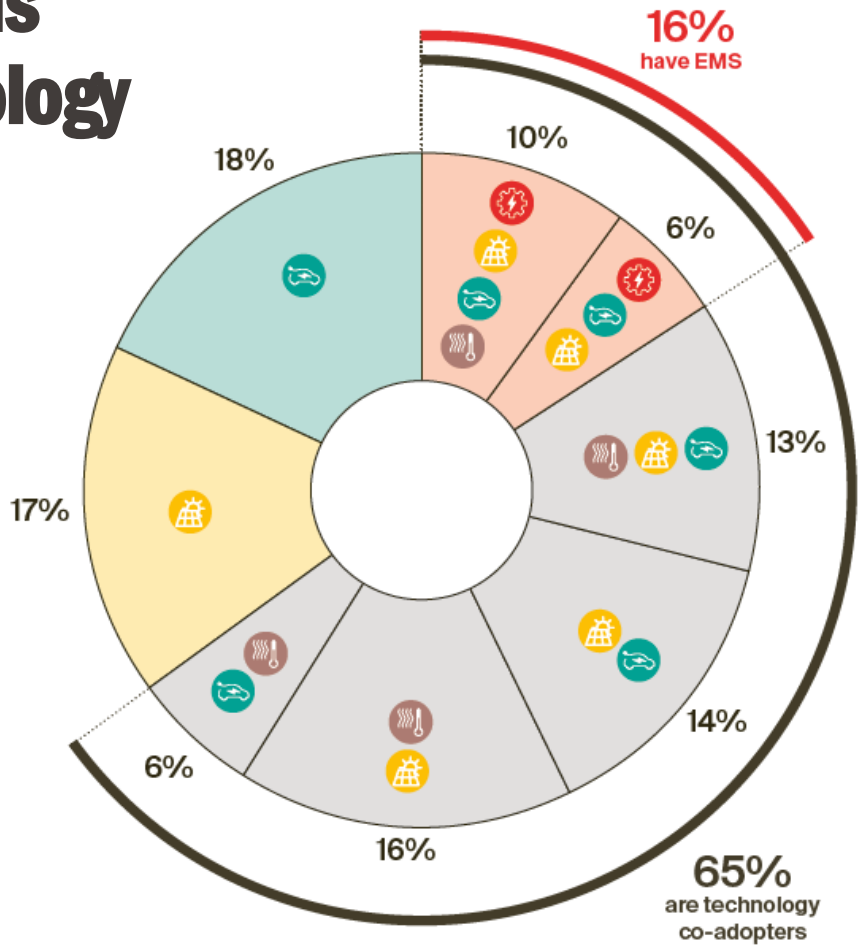
"... the sale of two or more separate products (goods or services) in one package."

Stremersch and Tellis, 2002: 57

*They offer **greater value** through complementarity, reduce perceived risk, and enhance convenience by saving time and effort spent on a purchase.*

Tellis and Stremersch, 2006

65% of households are energy technology co-adopters



HERUS, 2024; Hecher et al., 2025

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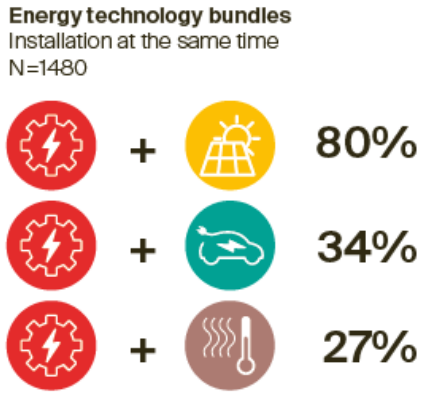
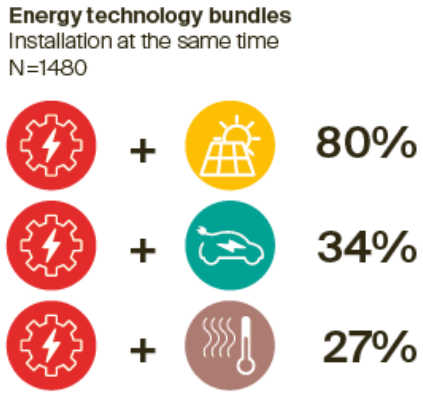
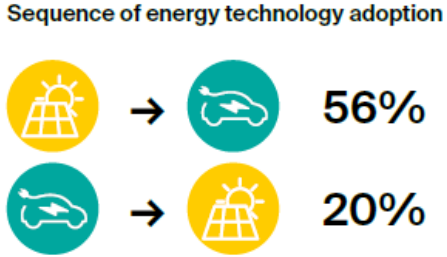
EMS mostly installed as a bundle with PV



Hecher et al., in preparation

PV seems to be a trigger technology for EV





Hecher et al., in preparation

Drivers and barriers for technology adoption

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PV adopter groups

	Early adopters	Potential adopters	Unlikely adopters	Total
Rooftop PV	900 18%	2,000 39%	2,200 43%	5,100 100%

Duygan et al., in preparation

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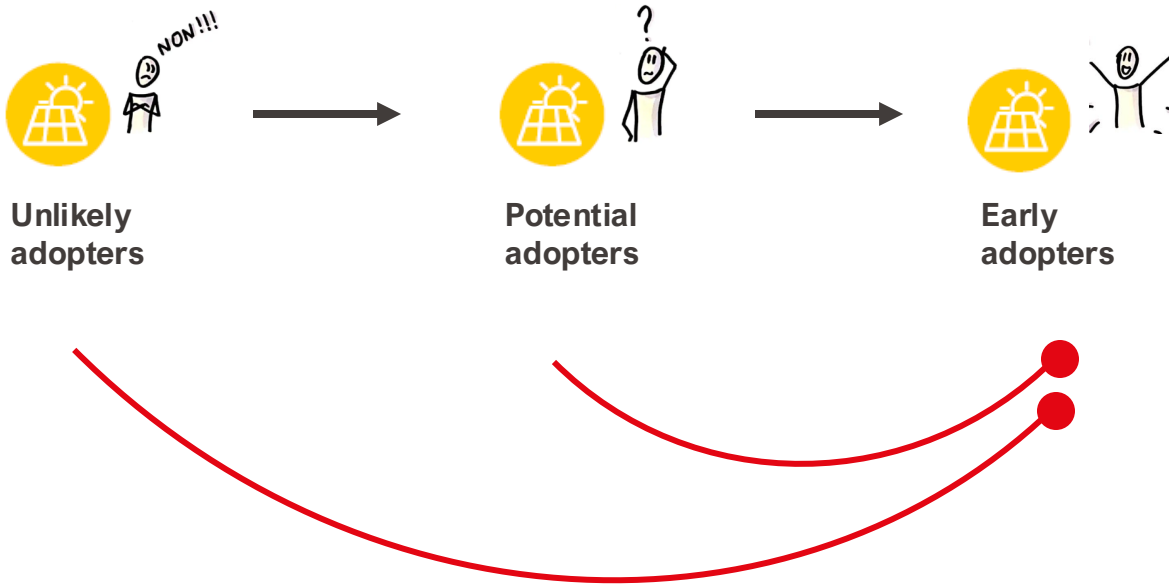
Are non-adopters a heterogeneous group?



Duygan et al., in preparation

Unlikely and potential adopters compared to early adopters

N=529

N=1098

		Unlikely adopters (early adopters) Odds ratio	**Potential adopters** (early adopters) Odds ratio
Socio-demographics	Age	**1.020 ****	
Personal context	Homeownership	**4.193 *****	
	Single-family house	**1.756 ****	**1.479 ****
	Electric car ownership	**7.255 *****	**2.362 *****
	Heat pump ownership	**3.107 *****	**2.265 *****
Perceived attributes	Perceived economic viability	**0.822 ***	**0.851 ***
Social influence	Professional information sources	**0.725 *****	
	Information exchange in personal network	**0.770 *****	**0.858 *****
	Presence of PV adopters in personal network	**3.001 *****	
Environmental attitude and policy	General environmental attitude	**0.955 ***	
	Pro-PV policy belief	**0.613 *****	
Trust	Trust in state authorities	**1.034 ***	

Duygan et al., in preparation

Strategies to promote PV adoption

- **Focus on potential adopters first:** Collect low-hanging fruits
- **Promote technology co-adoption:** Owners of electric vehicles and heat pumps are particularly keen to adopting PV
- **Leverage social contagion:** The presence of PV in personal networks positively influences adoption decisions

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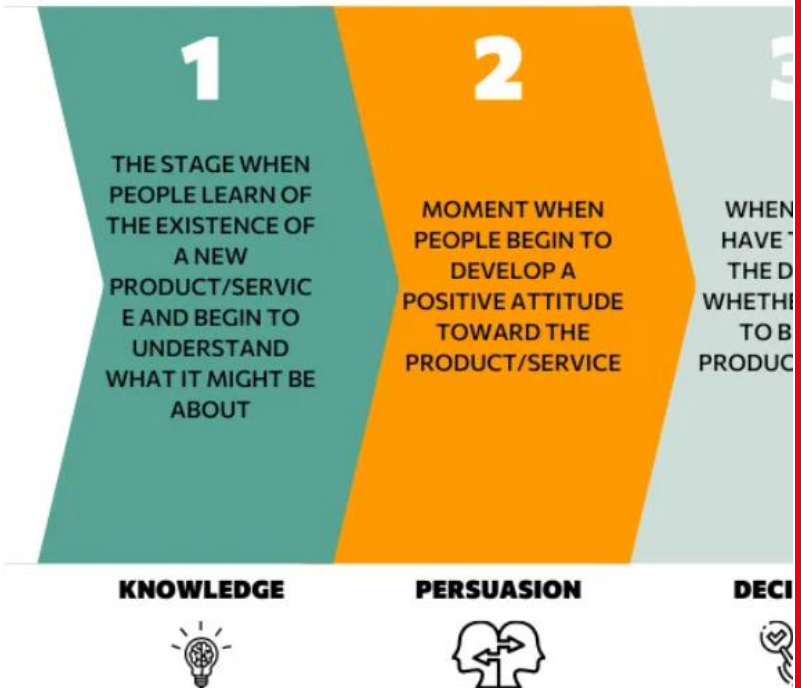
Technology adoption decision-making process

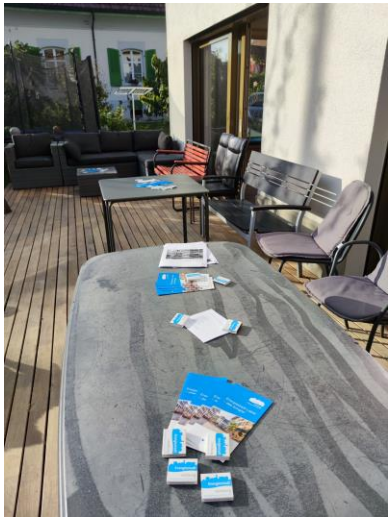


The process of PV adoption decisions

- Which factors influence the process of PV adoption and are conducive for a faster decision progress?
- What is the role of solar parties in the adoption process?

What is a solar party?

- Community-based event organized by local volunteers and supported by governments
- Host who adopted PV showcases installation, shares experiences, Q&A
- Input and support by neutral PV expert
- Apéro for informal exchange



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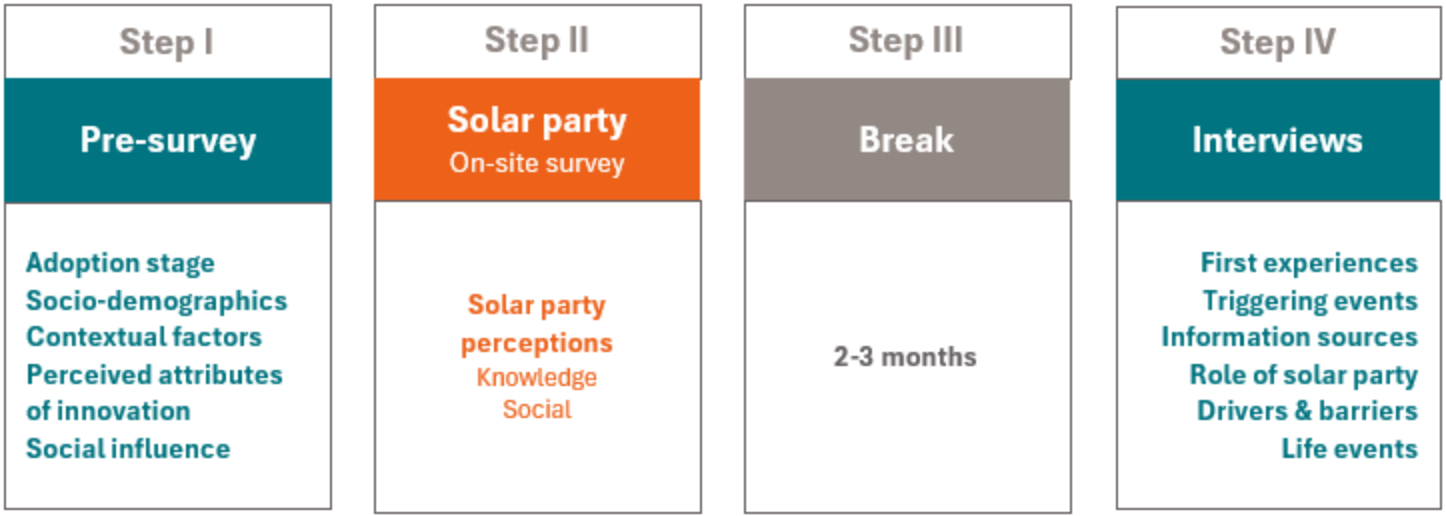
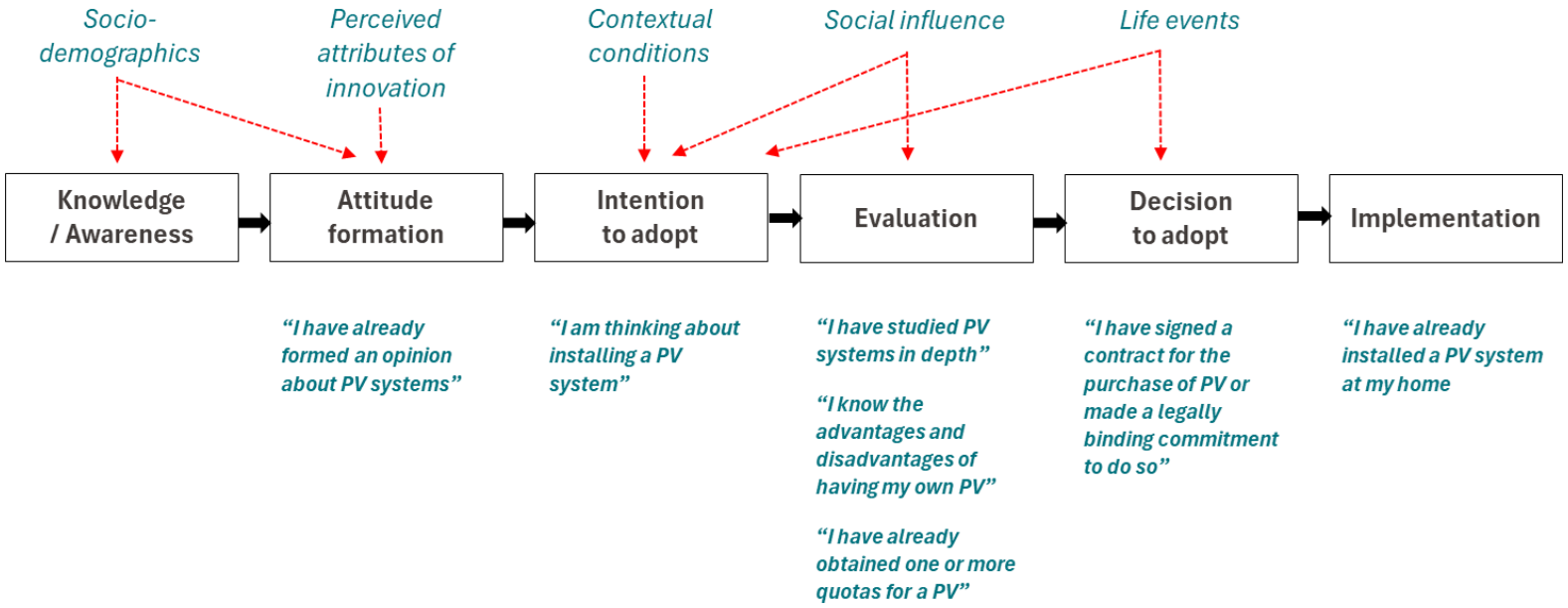
Research design



Hecher et al., in preparation

PV adoption stages



Rogers, 2003; Prochaska et al., 1992; Hecher et al., in preparation

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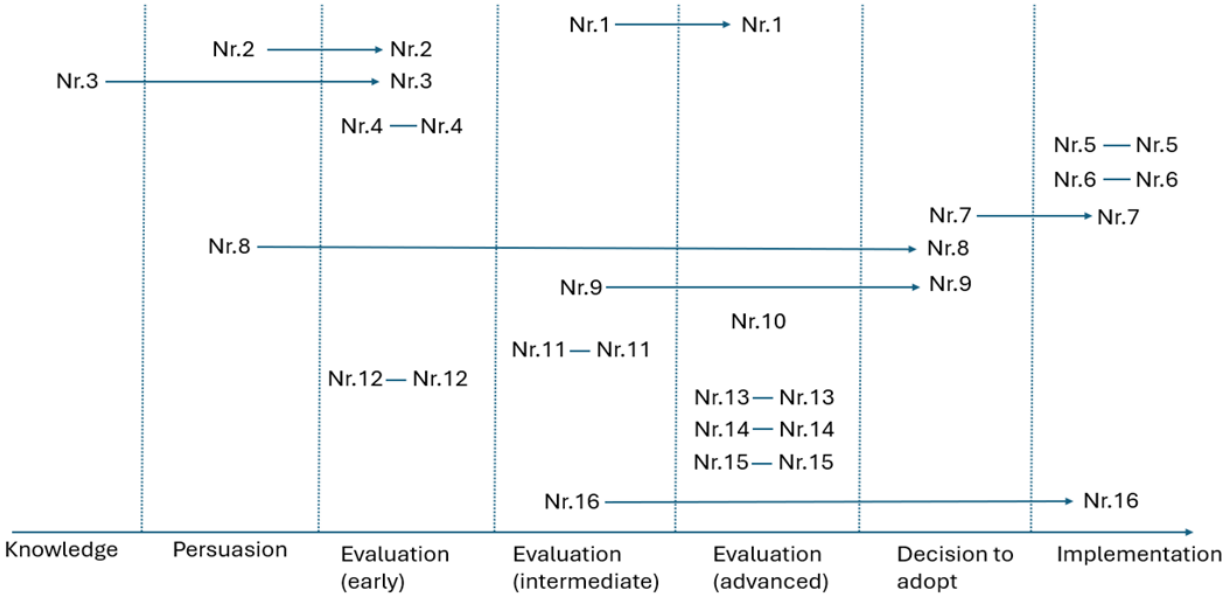
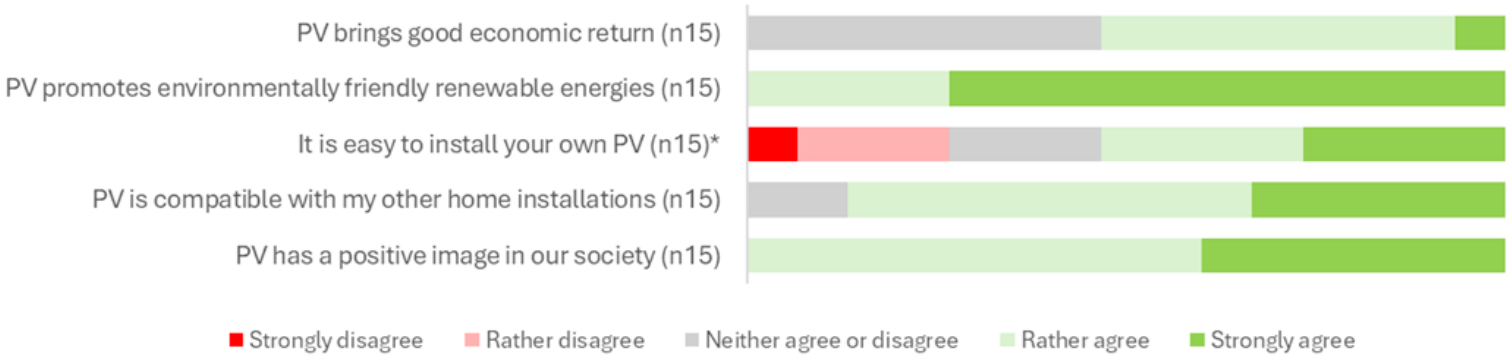
Slight majority made progress towards PV adoption



Hecher et al., in preparation

Positive perception of PV attributes is a necessary yet not a sufficient condition for PV adoption



Hecher et al., in preparation

First experiences and triggers

- **First experiences:** mostly date back many years ago
- **Building events:** renovations and heating system replacements
- **Life events:** moving in or taking over a new house
- **Peer effect:** PV installations in the neighborhood and solar parties
- **Accumulation of triggers**

"I think with the energy crisis since 2021/2022, it has been more of an issue, and we are currently discussing it with several neighbors, maybe doing something together and when I got this flyer in my mailbox, I thought, okay, if something is happening here a few minutes' walk away, then I'll stop by."

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Hecher et al., in preparation

Drivers and barriers

	Drivers	Barriers
Micro *Individual or household level*	Financial savings Energy independence Technical interest Time	Insufficient knowledge Lack of time Personal circumstances Financial constraints
Macro *Common good, market, building level*	Contribution to energy transition, environment and future generations	Insufficient roof conditions Lack of compatibility across technologies Contradictory information Disagreement with neighbors

Hecher et al., in preparation

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Social influence

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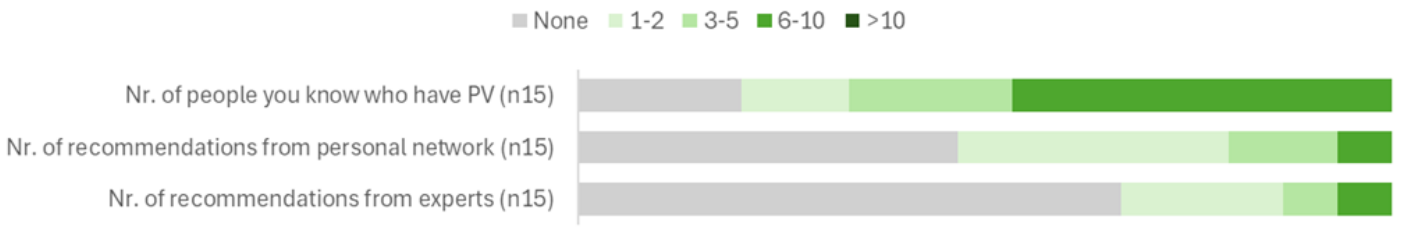
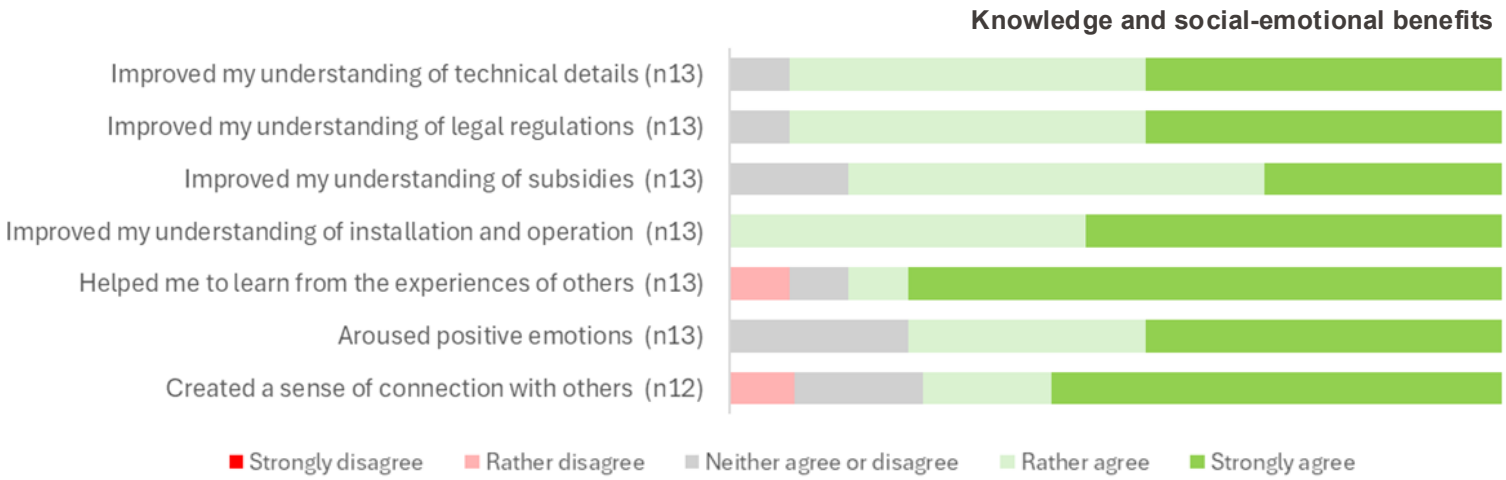


Hecher et al., in preparation

Perceptions about solar parties



Hecher et al., in preparation

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Factors leading to progress towards adoption

	Participants without progress (6)	Participants with progress (7)
Solar party perceptions	Knowledge: Ø 4.10 Social-emotional: Ø 4.10	Knowledge: Ø 4.55 Social-emotional: Ø 4.47
Social influence	Majority lacked recommendations from personal network or experts (4/6)	Slight majority received recommendations from personal network (4/7)
Perceived economic viability	Majority does not agree that solar PV brings a good economic return (4/6)	Majority agrees that solar PV brings a good economic return (4/7)
Information	Often cite lack of knowledge	Often cite contradictory information
Building type	2 out of 3 who live in multi-family houses did not show progress	None of those who implemented or reached a decision to adopt live in multi-family houses

Hecher et al., in preparation

Solar parties can boost adoption progress

- Can serve as a **trigger** for developing an intention to adopt.
- Spatial proximity of solar parties generates **trust**.
- Can address **knowledge barriers** and provide neutral information.
- Can reduce **economic uncertainty** and support multi-family house owners

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Hecher et al., in preparation

Integration of human behavior in energy transition models

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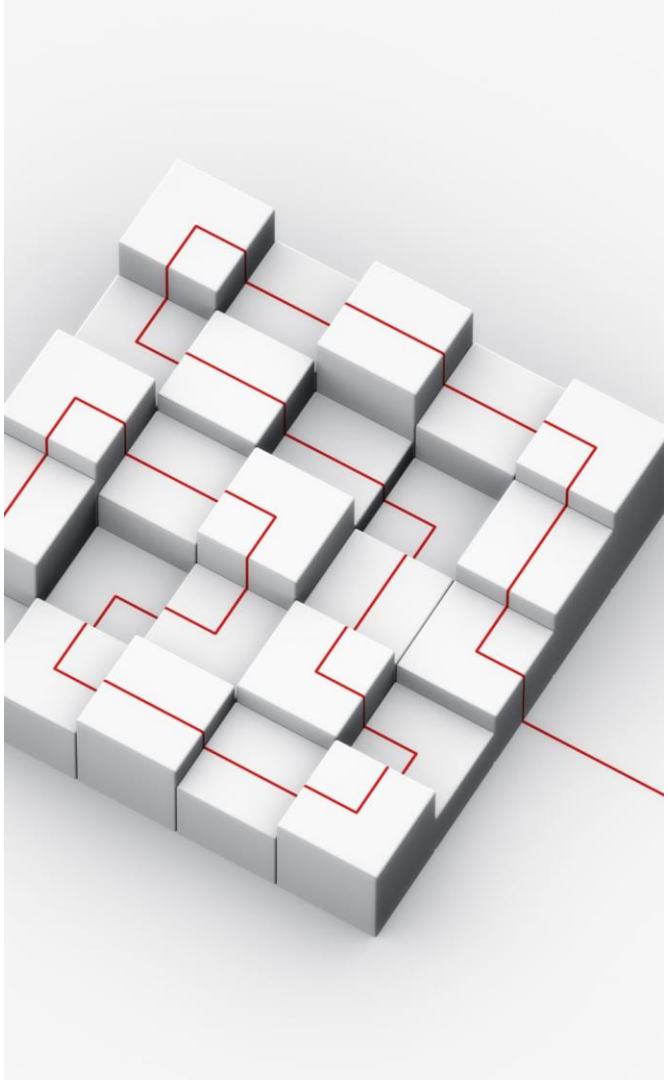
What is a model?

"(…) all models are approximations. Essentially, **all models are wrong, but some are useful.** However, the approximate nature of the model must always be borne in mind."

George Box (1987)

Agent-based model for spatial energy planning

- Spatial-explicit, empirically grounded agent-based model (ABM) to simulate urban transitions
- Tool to support cities in spatial energy planning
- Integration of human-behavior in building models
- Science-policy interface



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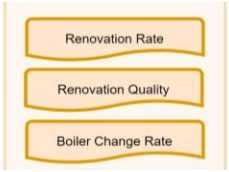
Modelling approach

Parameterization

User input

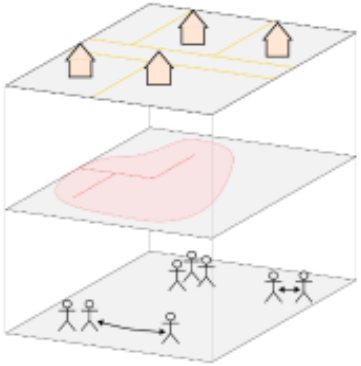


Financial incentives

Regulations

Initialization

Model setup



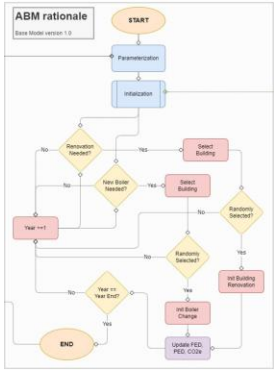
Building data

Infrastructure and energy potential data

Household attributes

Simulation

ABM Model



Output

Energy demand by energy carrier, CO_2 emissions, etc.

Use cases

City planners, energy analysis, district heating operators, and citizens

- Energy transition scenarios
- Assessment of energy policies
- Municipal heat planning

Technical model

Christophe Ballif / Philippe Thalmann / Claudia Binder

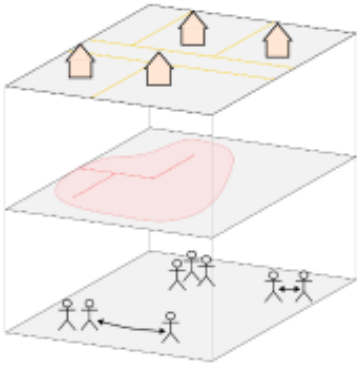
Parameterization

User input

- Renovation Rate
- Renovation Quality
- Boiler Change Rate
- Boiler Prioritization
- New Construction Rate
- Demolition Rate
- Year End of Experiment

Initialization

Model setup



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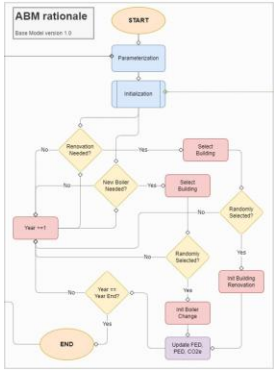


Candidates

Renovate

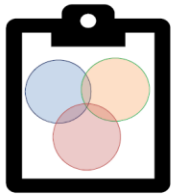
Building age (> 25y)

Modernize

Heating system age (> 30 years higher priority, 20-29 lower priority)

Empirical study on households' renovation decisions

Online survey on energy renovation decisions



Final sample of 1,787 homeowners from across Styria

PLS-SEM to understand household decision-making

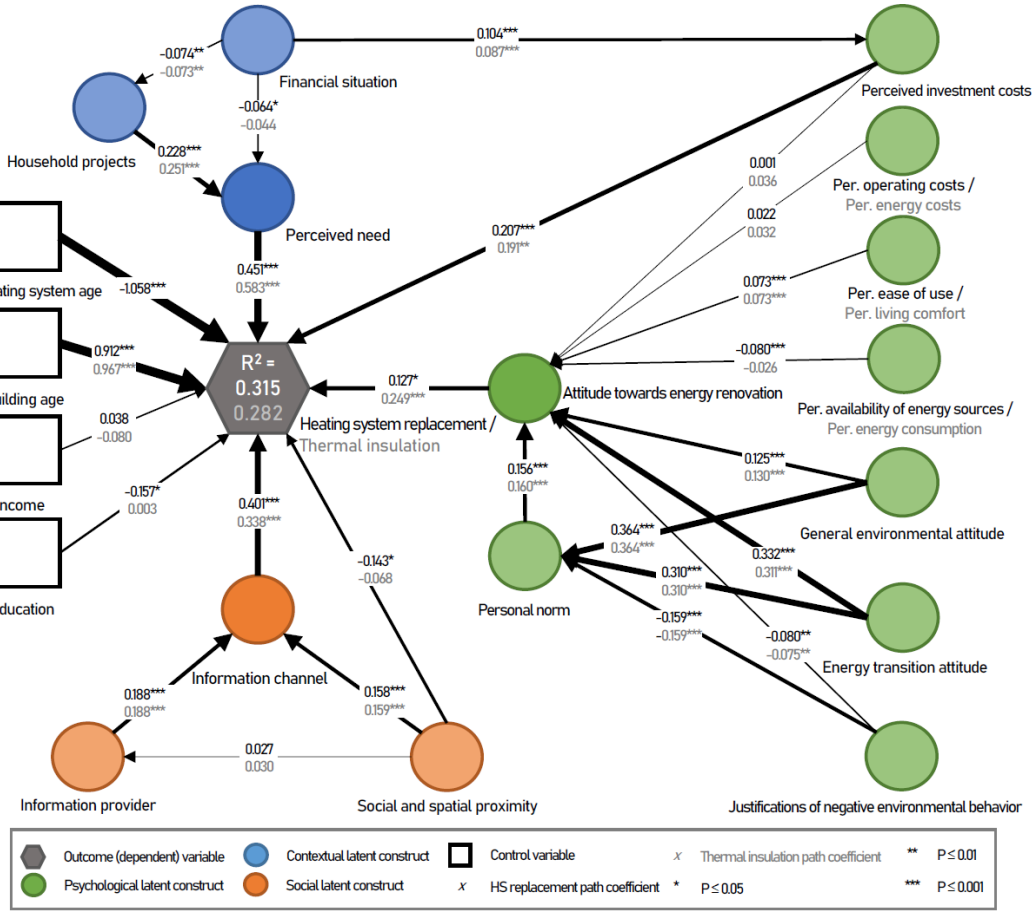
Integration of rules and parameters for **household decision-making** in the ABM

Christophe Ballif / Philippe Thalmann / Claudia Binder

Drivers for building renovations

1

- Perceived need
- Information for planning phase
- Attitude towards energy renovation



Ladino Cano et al. (in preparation)

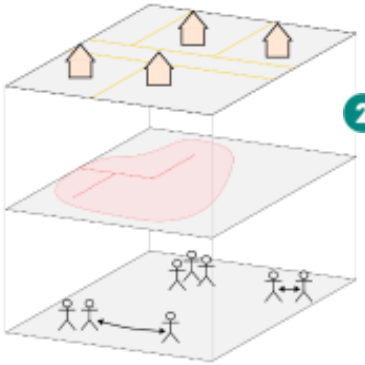
Technical model extended with human behavior

Christophe Ballif / Philippe Thalmann / Claudia Binder

Parameterization
User input

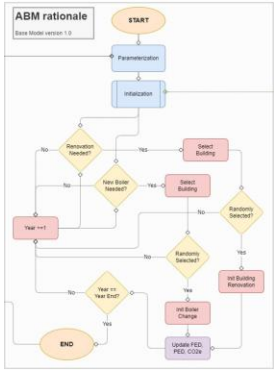
3
Financial incentives
Regulations
Social influence

Initialization
Model setup



2
Building data
Infrastructure and energy potential data
Household attributes for residential buildings

Simulation
ABM Model



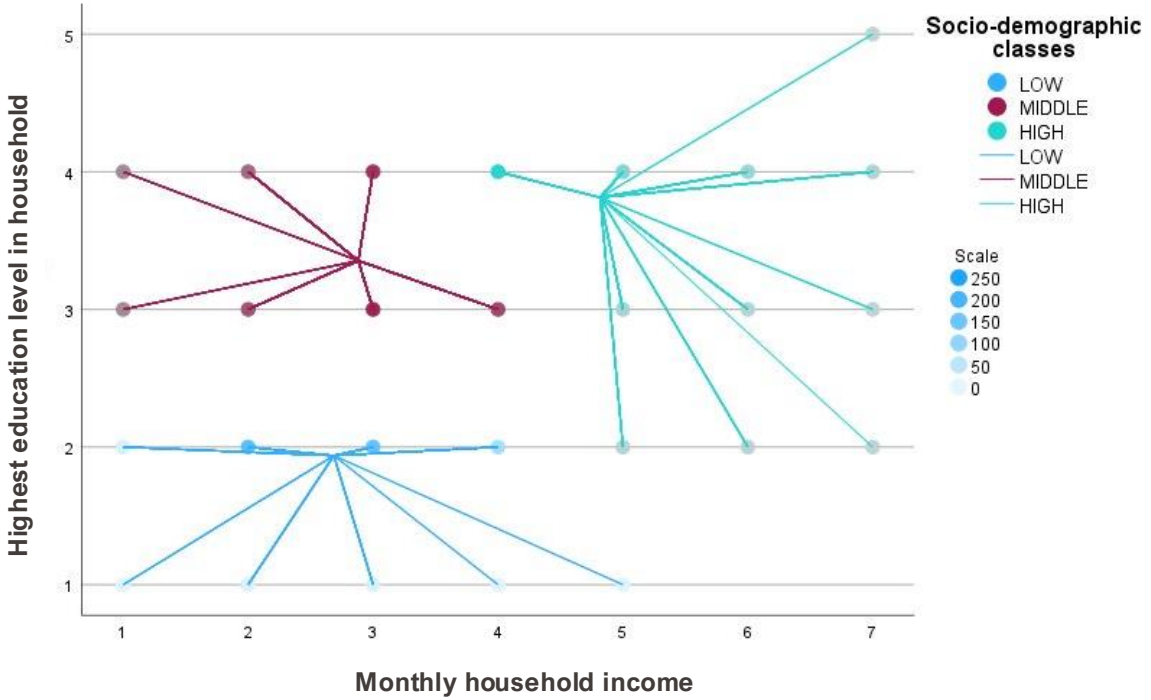
1
Candidates

Renovate
Building age (> 25y)
Homeowners' decision (utility function)

Modernize
Heating system age (> 30 years higher priority, 20-29 lower priority)
Homeowners' decision (utility function)

Attributes for socio-demographic classes

2



Technical model extended with human behavior

Parameterization
User input

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Financial incentives
Regulations
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Initialization
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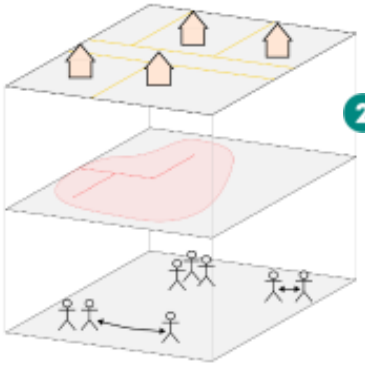

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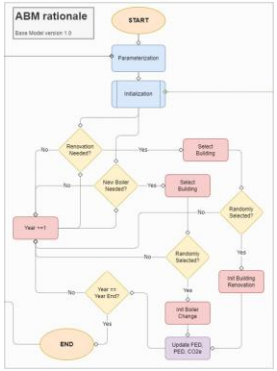

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Homeowners' decision (utility function)

Christophe Ballif / Philippe Thalmann / Claudia Binder

Policies

3

- **Financial incentives**
  subsidies, grants…
- **Social-norm based interventions**
  information campaigns, technical assistance programs…
- **Environmental standards**
  regulations, green labels…

Renovation

Factor	Parameter	POL1	POL2	POL3
Attitudes	Energy transition attitude			+0.40
	General environmental attitude			+0.30
	Justifications of negative environmental behavior			-0.20
	Personal norm			+0.40
	Perceived energy consumption	-0.35		
	Perceived living comfort		+0.70	
	Perceived investment costs	-0.40		
Household context	Perceived need	+0.20		
Social influence	Information provider		+0.50	
	Social and spatial proximity		+0.40	

Christophe Ballif / Philippe Thalmann / Claudia Binder

Technical model extended with human behavior

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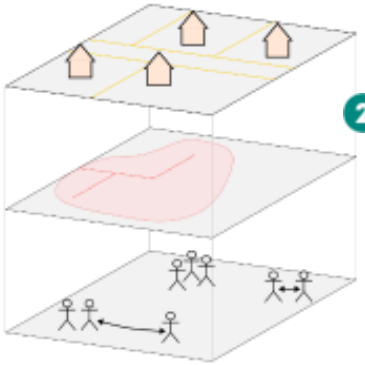

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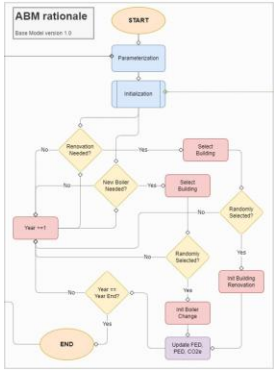

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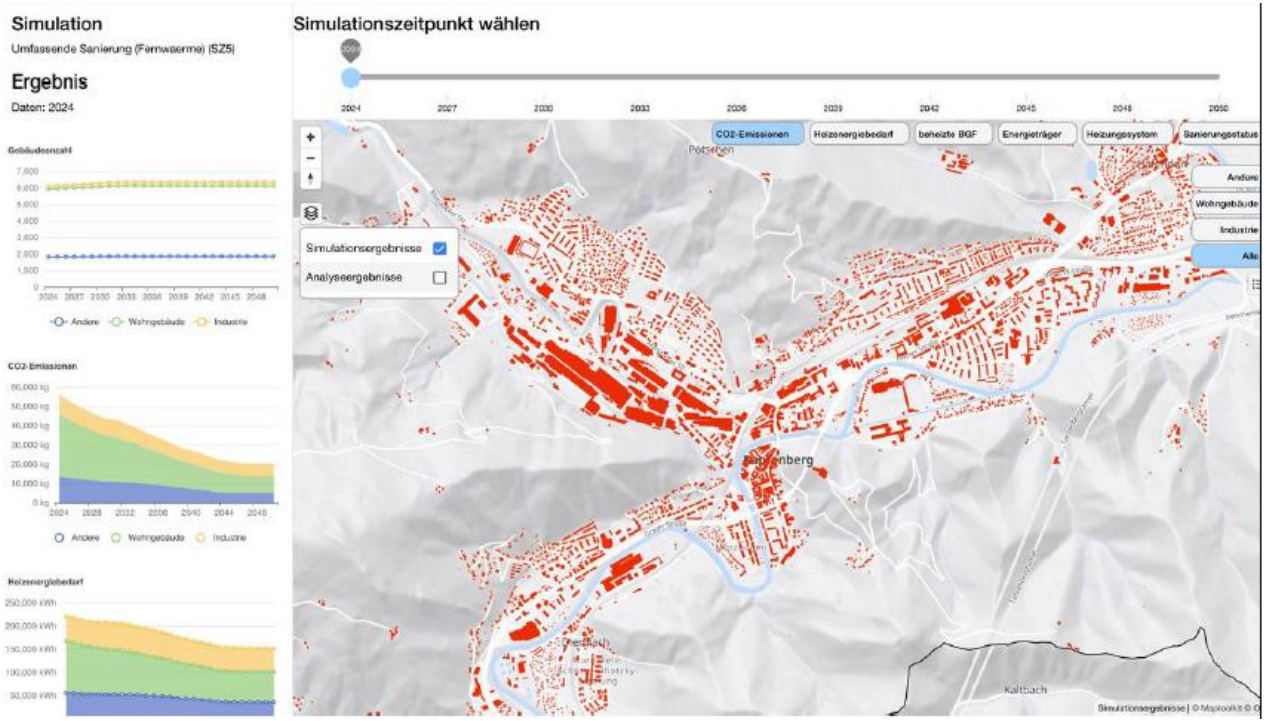
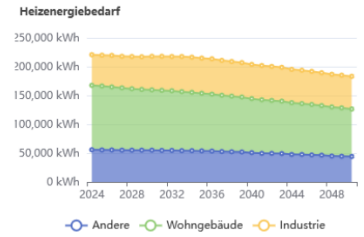
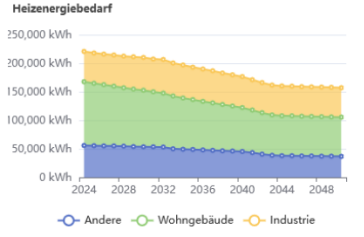
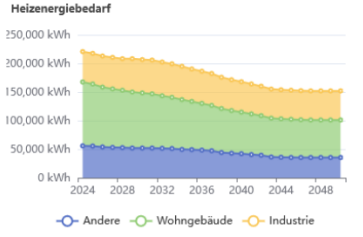
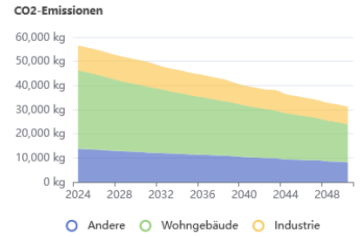
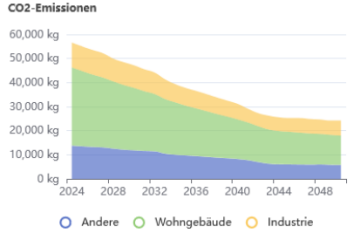
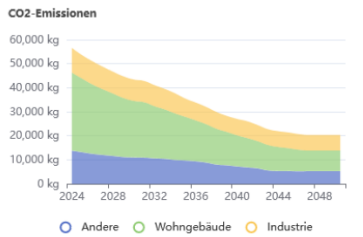
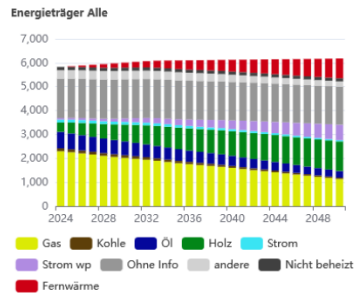
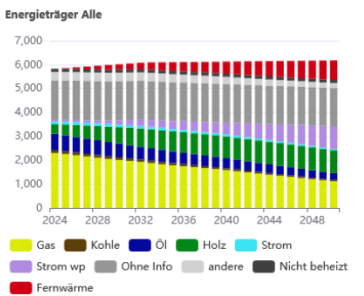
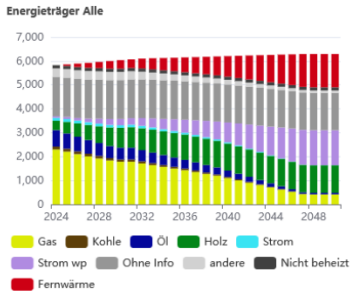
Demonstrator: Spatial-explicit expert view



Christophe Ballif / Philippe Thalmann / Claudia Binder

Demonstrator: Scenario results comparison

Scenario	S1 – Business As Usual	S2 – Thermal Refurbishment	S5 – Comprehensive Refurbishment – DH
Heating Energy Demand (HED delivered)			
CO2 Emissions			
Energy Carriers			

Science-policy interaction

Stakeholder workshop
October 2024

Key messages

- Technically and economically viable solutions can still fail without social acceptance.
- Policies to support innovation diffusion must account for the diverse characteristics of both adopters and non-adopters.
- Windows of opportunity should be actively used to promote technology (co-)adoption and accelerate the diffusion of emerging technologies.
- Social influence plays a crucial role and can be strengthened through trust and spatial proximity.
- Consumer preferences must be integrated into current energy models to achieve more realistic and robust outcomes.

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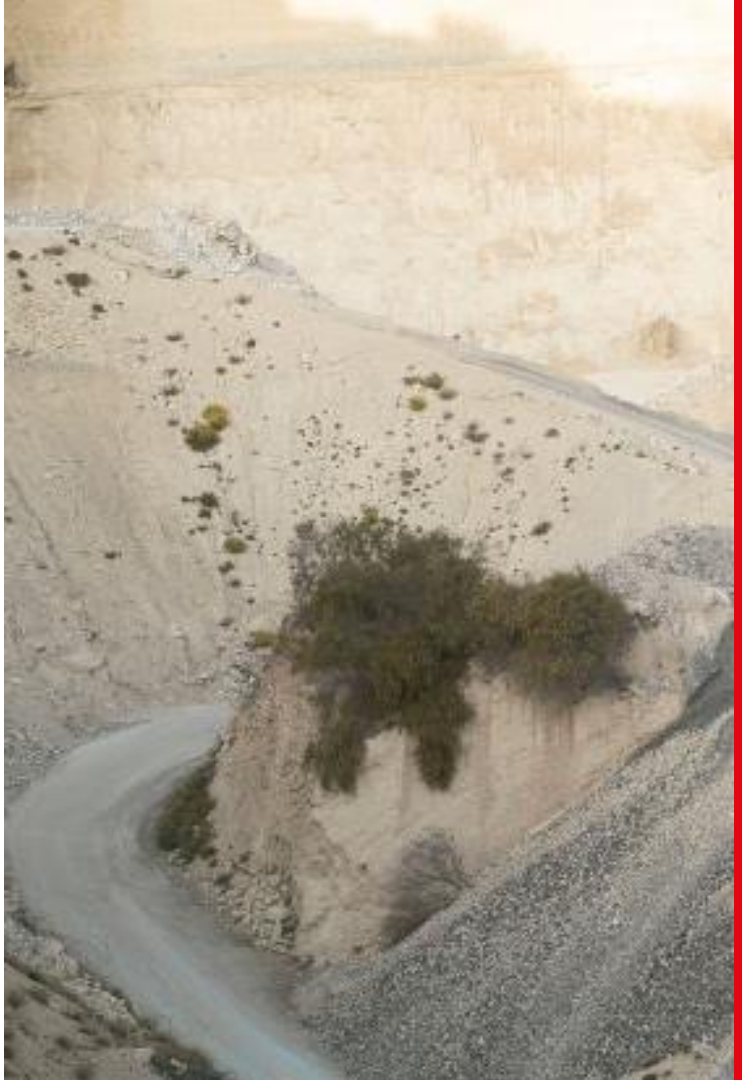
EPFL



ENERGY SUPPLY, ECONOMICS AND TRANSITION

Thank you!

Maria Anna Hecher
maria.hecher@epfl.ch