ENERGY SUPPLY, ECONOMICS AND TRANSITION

ENV-410
Energy supply, economics and transition: Integrative analysis of the energy transition

Prof. Claudia R. Binder

Laboratory for Human-Environment Relations in Urban Systems

April 16th, 2025

Urbanization: Opportunity and challenge

Although urban areas only cover 3% of the Earth's surface, they…

house more than
50%
of the global population

generate more than
80%
of global economic activity

consume
75%
of global resources

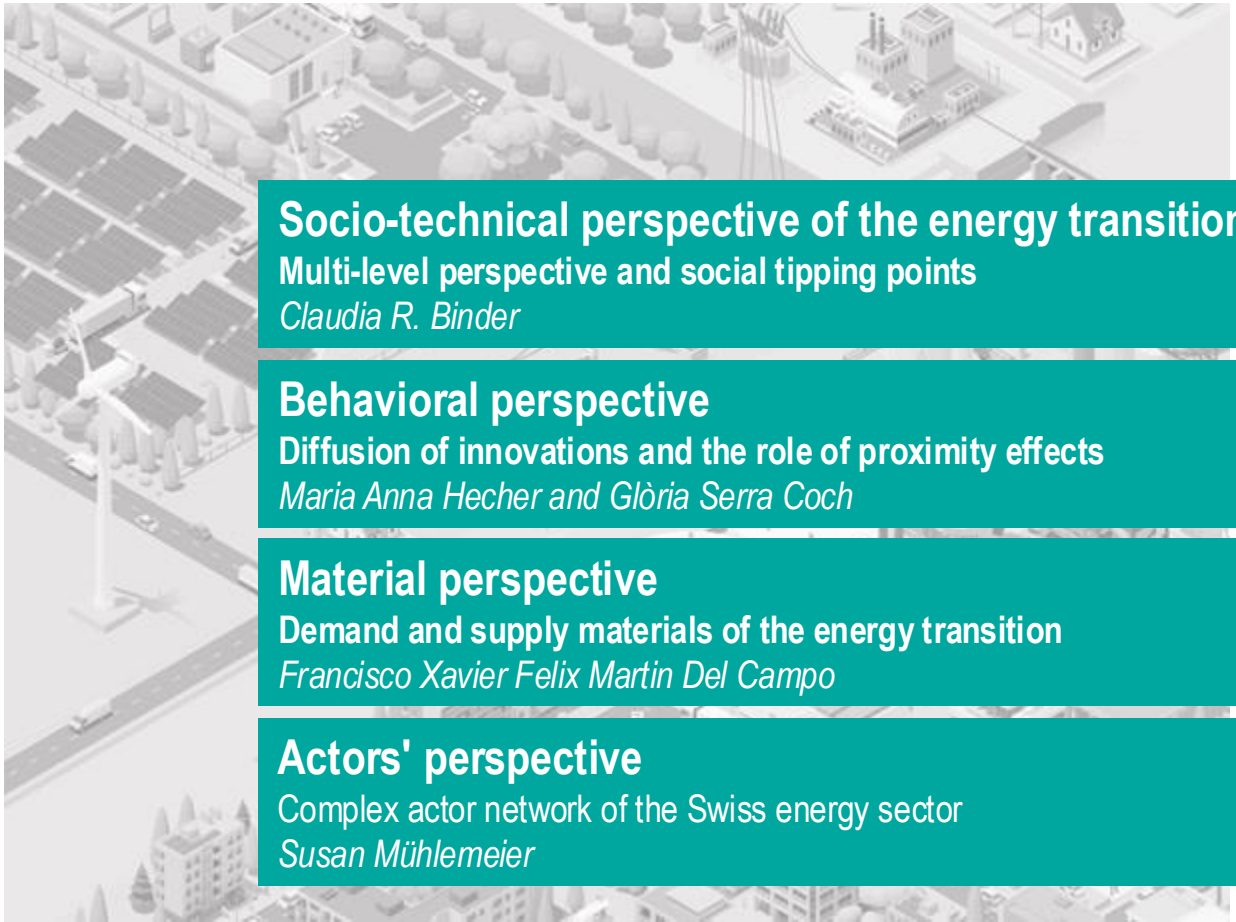
produce
75%
of global emissions

Christophe Ballif / Philippe Thalmann / Claudia Binder

Energy transition perspectives

Christophe Ballif / Philippe Thalmann / Claudia Binder

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

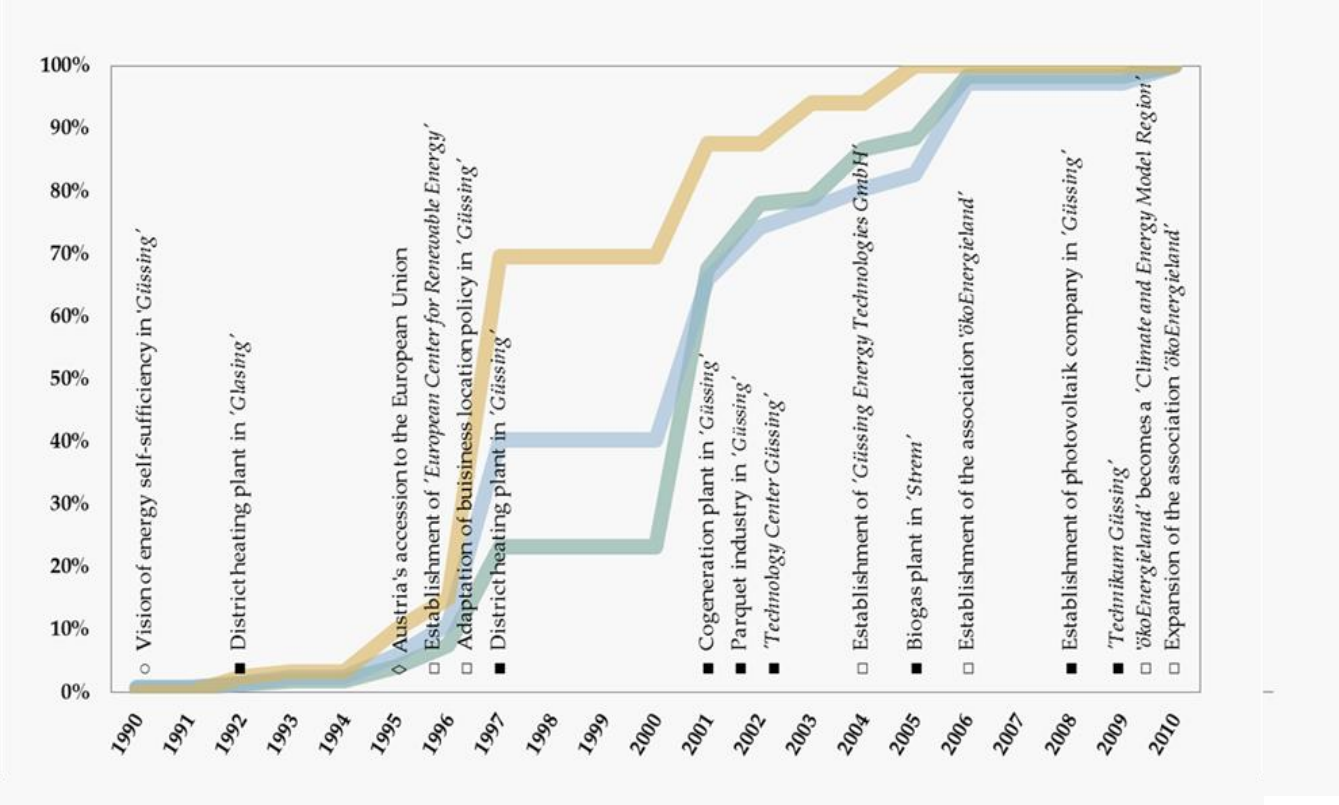
Actors' perspective

Complex actor network of the Swiss energy sector

Susan Mühlemeier

Socio-technical perspective

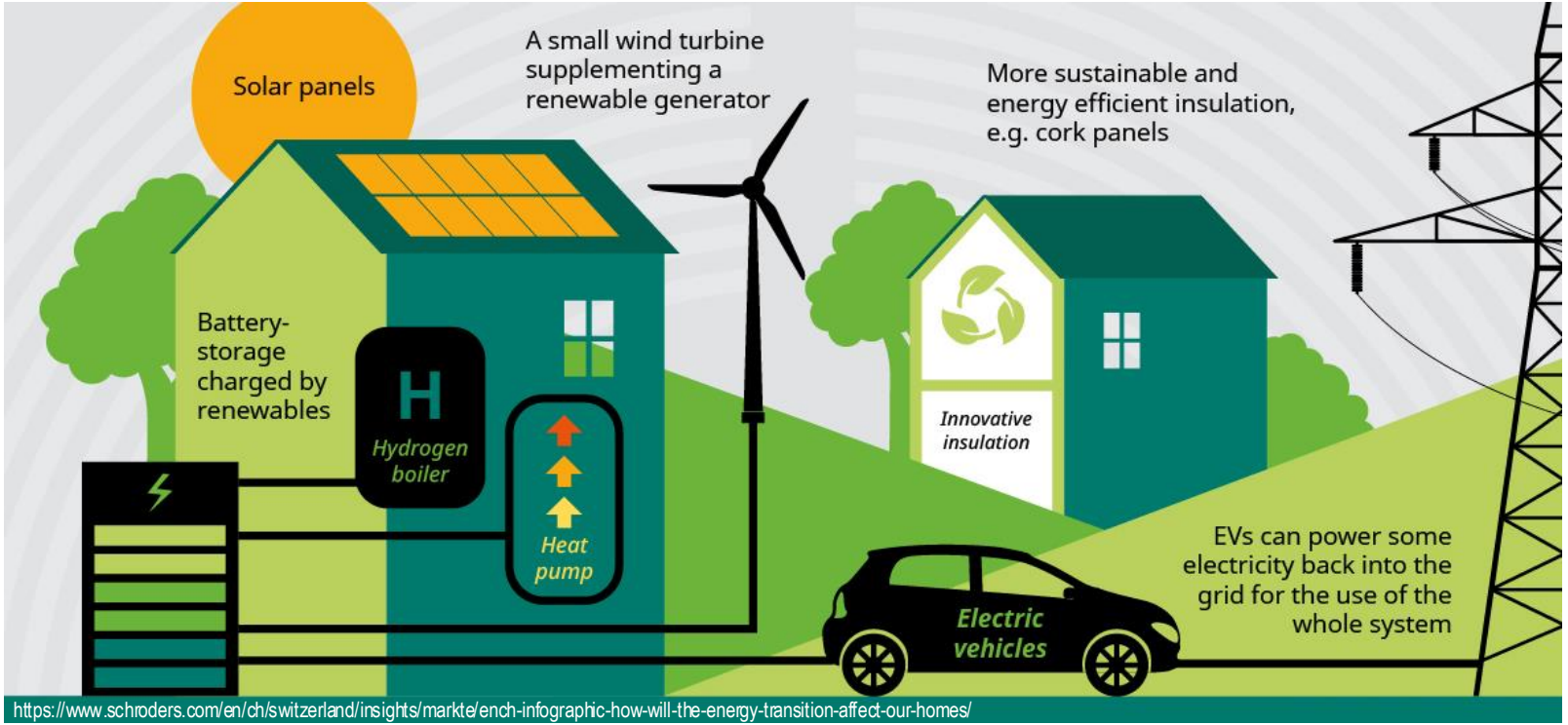
Significant time delay between vision and impact on energy flows



Source: Hecher et al. 2016

Behavioral perspective

Drivers and barriers for energy technology adoption decisions and the role of social networks



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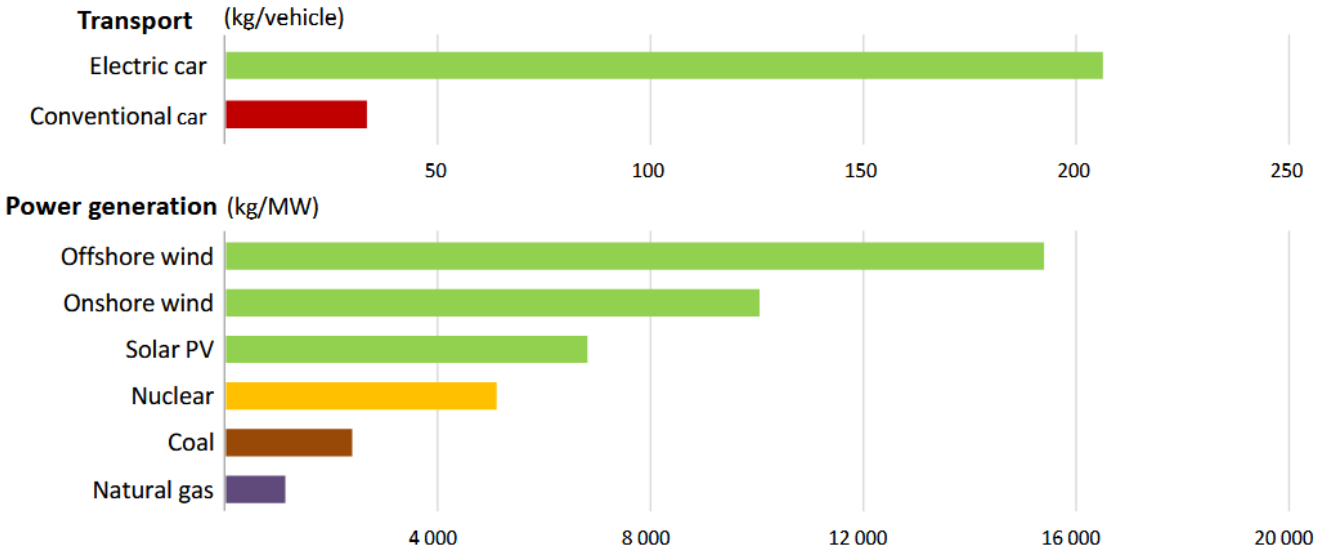
Material perspective

Minerals used in selected energy technologies



Source: IEA, 2021

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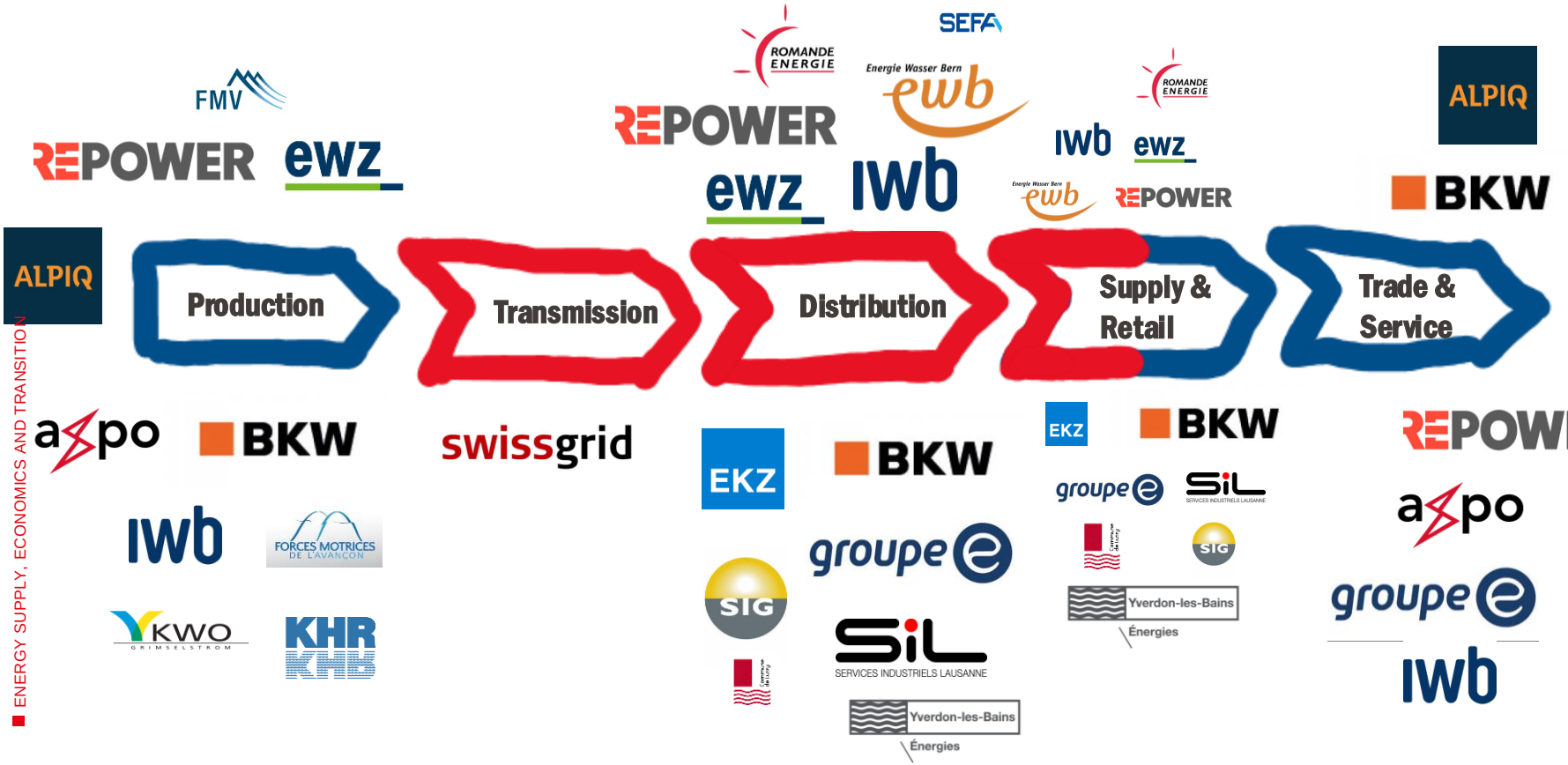
Social perspective

Key actors in the Swiss electricity value chain



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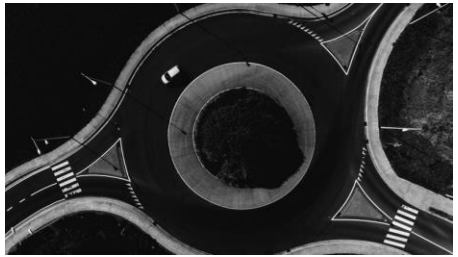
Apply for master and semester projects

Urban metabolism



Sustainability assessment

Energy transition

Send us your CV and motivation letter with specific topic, research questions and methods you want to use.

All applications and questions should be sent to: matthias.heinrich@epfl.ch

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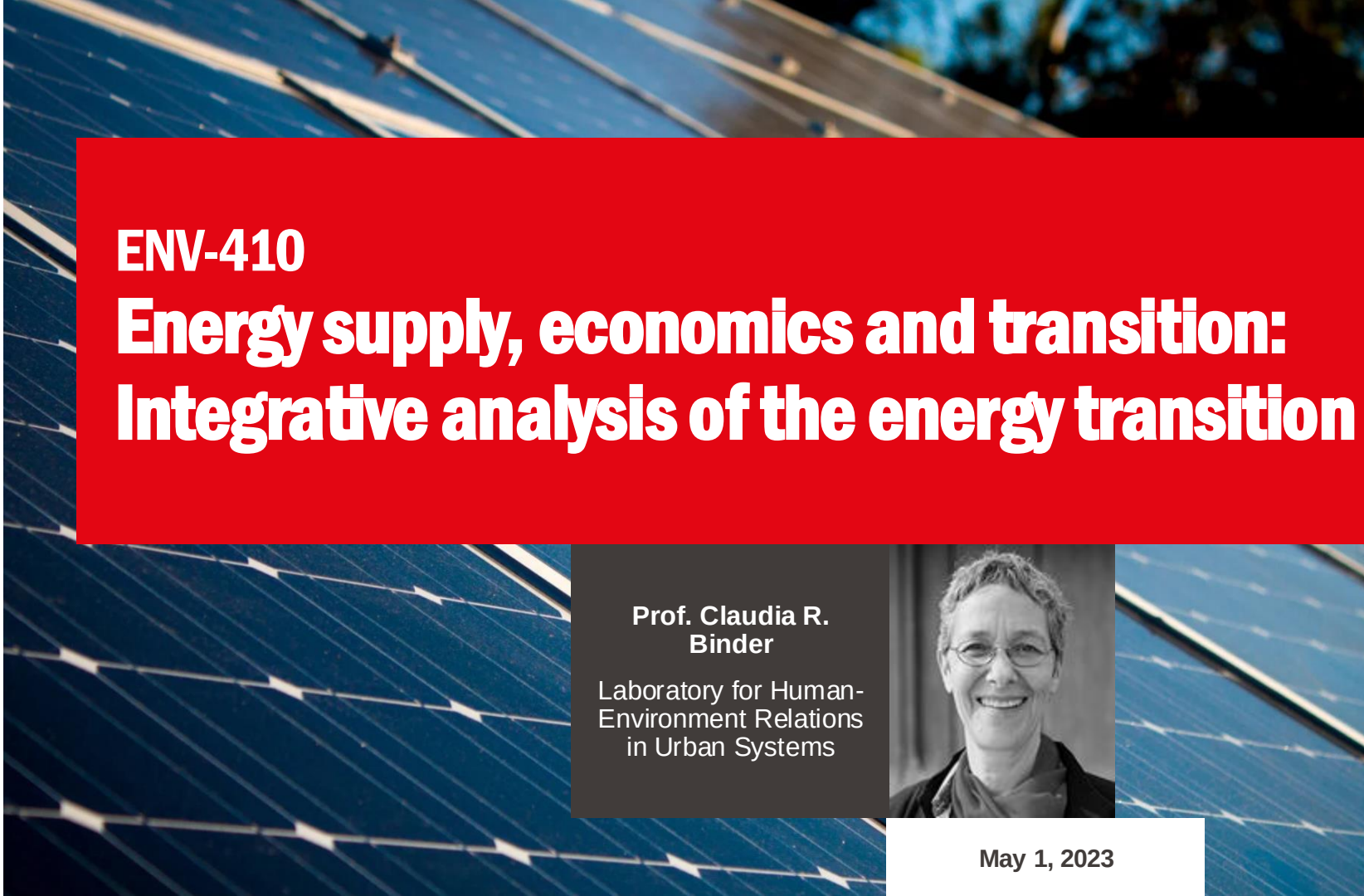

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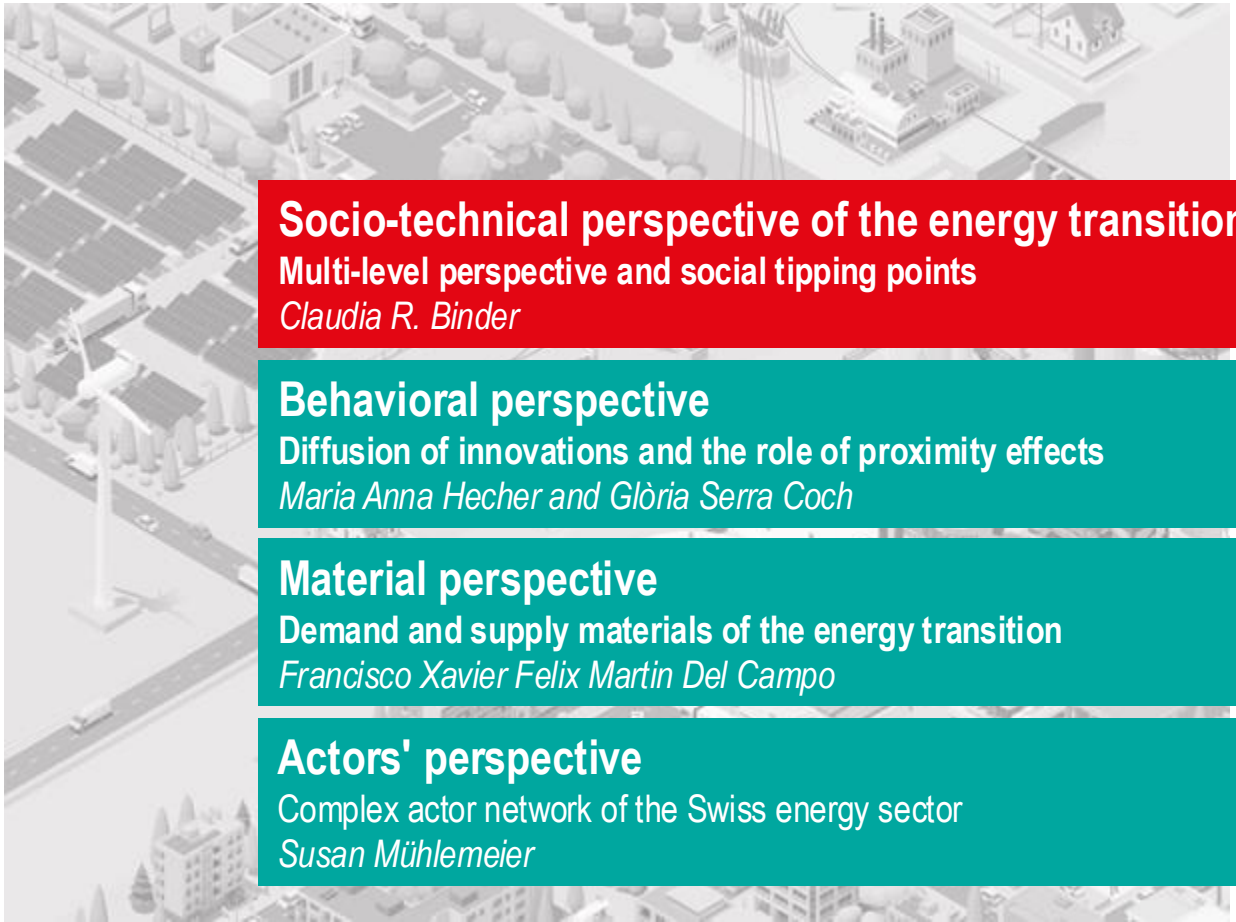
Laboratory for Human-Environment Relations in Urban Systems

May 1, 2023

Energy transition perspectives



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Goals

- Comprehend the key phases of transitions
- Understand the relation between the social and technical systems during the transition
- Appreciate the concept of tipping points, drivers and barriers and their role in transitions

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Key messages

- The energy transition is not the energy transition
- The social and technical systems are deeply interlinked
- The way the systems “interact” might differ at different "spatial and temporal scales”

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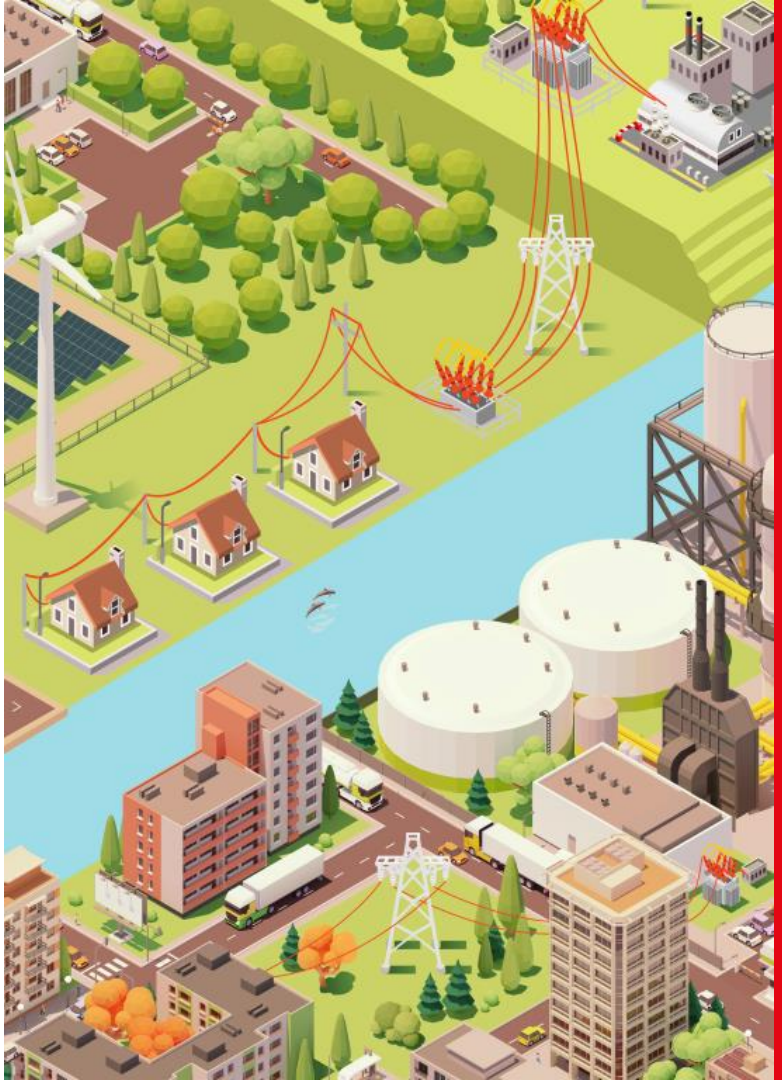

What is a transition?

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Transition ...

... or evolution?

Source: Courtesy and Wyss, 2020

Changing practices

1970

2020

Source: Courtesy and Wyss, 2020

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What is first?

Technology ...

… or social need?

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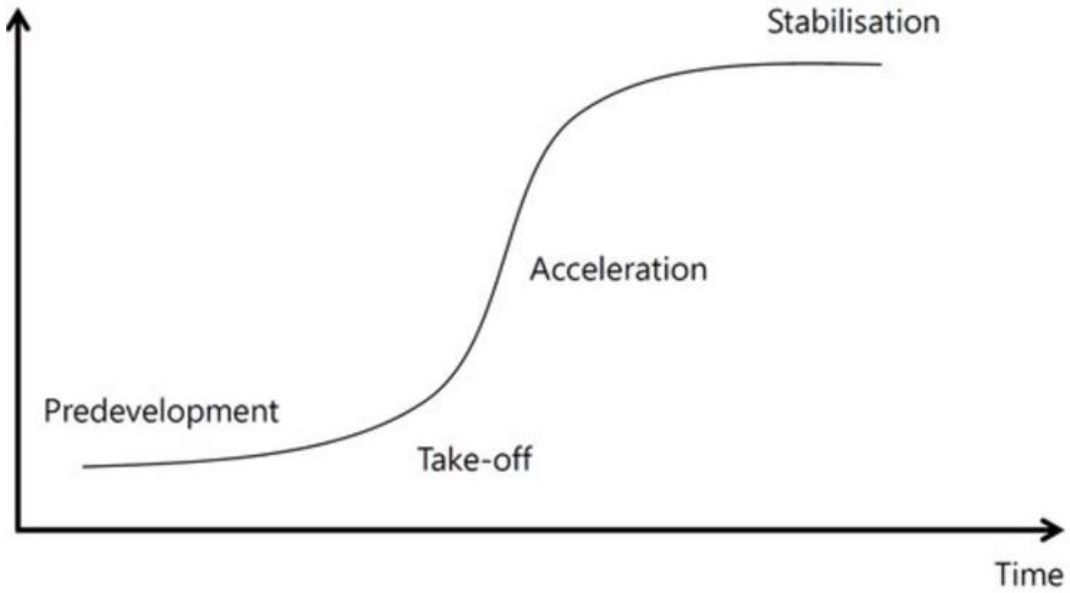
Multi-phase perspective of transitions



Source: Rotmans et al., 2010

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Pre-development & Kick-off phase

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Acceleration phase

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Stabilisation phase

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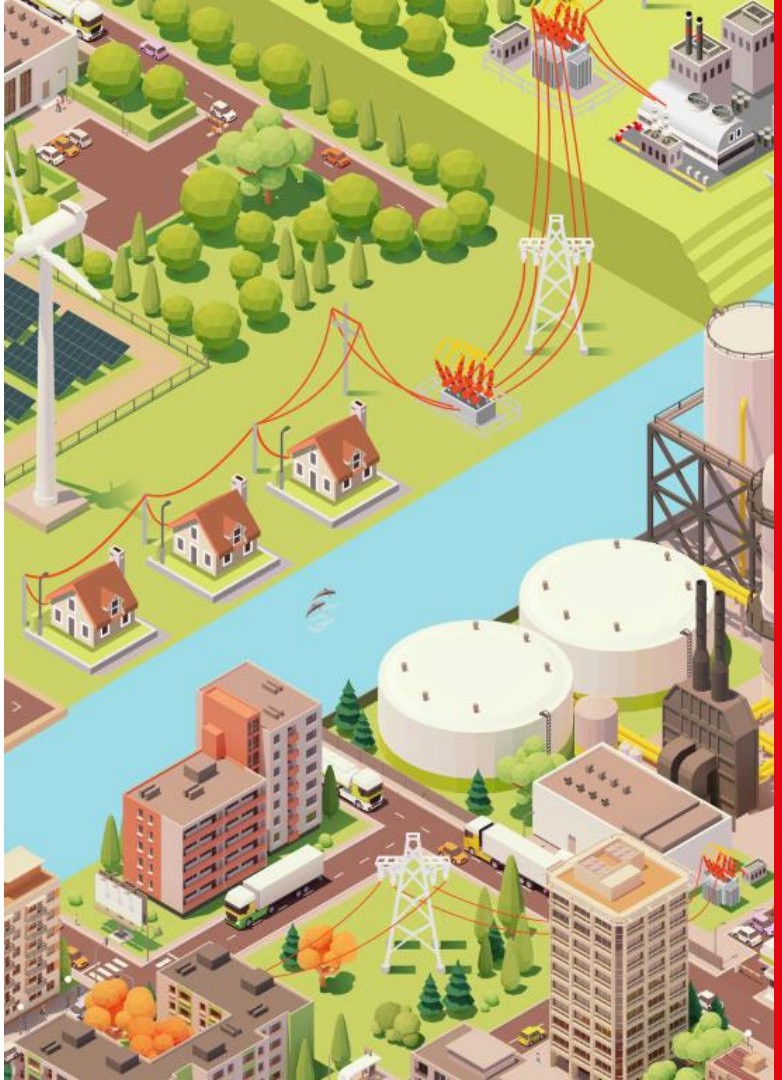

What are the issues in energy transitions?

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Issues in energy transitions

[24] LE MATIN DIMANCHE

S'abonner

E-paper LMD Abonnements Impressum

Accueil | Le Matin Dimanche | Transition énergétique: Chauffage des bâtiments: les vendeurs de mazout font de la résistance

Abo Transition énergétique

Chauffage des bâtiments: les vendeurs de mazout font de la résistance

Swissoil a entamé une série de séances d'information à travers la Suisse romande pour convaincre les propriétaires de rester aux énergies fossiles.

Ivan Radja
Publié: 20.11.2022, 12h54

20

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SUISSE

Le bois, un joker pour la transition énergétique, selon un rapport

Publié il y a 2 semaines, le 19 avril 2023
De Keystone-ATS

ma RTS INFO SPORT CULTURE PLAY RTS AUDIO TV PROGRAMME TV MÉTÉO LA RTS PLUS

RTS Info

INFO TV RADIO UKRAINE SUISSE MONDE ENVIRONNEMENT ECO SPORT

Éviter le black-out: la Suisse face au défi des pénuries d'électricité

L'électricité est sans doute l'énergie la plus importante et la plus cruciale que nous consommons. Il s'agit aussi d'une énergie qui est directement produite en Suisse, contrairement aux énergies fossiles.

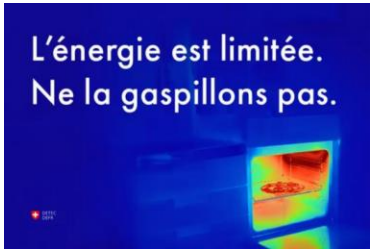
La question de la transition énergétique, et avec elle les enjeux liés au nucléaire et aux énergies renouvelables comme le solaire ou les éoliennes, est capitale. Mais depuis quelques mois, le spectre du black-out est brandi par la Confédération, qui craint des pénuries d'électricité dans le futur.

RTS La Première a consacré lundi une journée spéciale pour thématiser et explorer ces enjeux liés à l'électricité. Pour l'émission Forum, la rédaction était en direct depuis le barrage d'Emosson, en Valais. Cette page regroupe les contenus qui y ont été diffusés.

Adaptation web: Antoine Schaub

Christophe Ballif / Philippe Thalmann / Claudia Binder

Issues in energy transitions



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LE TEMPS

EN CONTINU MONDE SUISSE ÉCONOMIE OPINIONS CULTURE SOCIÉTÉ SCIENCES SPORT CYBER DATA ÉVÉNEMENTS VIDÉOS PODCASTS Chappatte

Abandon et gel des projets: en Valais, les premiers effets de la votation sur les parcs solaires alpins

La commune d'Orsières a décidé d'abandonner son projet de centrale solaire alpine, alors que celle de Leytron a gelé le sien. Des décisions qui font suite au refus des Valaisans d'accélérer la procédure d'autorisation des grandes installations photovoltaïques

HEIDI.NEWS
LES SCIENTIFIQUES DE L'INFO

ÉDUCATION SCIENCES ALIMENTATION DOSSIERS LES EXPLORATIONS NOS TABLEAUX DE BORD

Black-out: le talon d'Achille électrique de la Suisse | épisode N°04

L'invraisemblable retard solaire de la Suisse

La stratégie suisse de sortie du nucléaire et des énergies fossiles mise surtout sur l'électricité solaire. Depuis quatre ans, on installe cependant trois fois moins de panneaux que ce qui serait nécessaire. Et la baisse de la production en hiver reste un casse-tête. Alors pourquoi pas les Alpes, où le soleil brille autant que dans le Sud de l'Italie?

Christophe Ballif / Philippe Thalmann / Claudia Binder

Issues in energy transitions

- Energy transition is a complex issue encompassing technical, ecological and social domains
- Multi-scalarity and multi-dimensionality
- Technological, institutional, and social “lock-ins”
- Technological innovations alone are not sufficient for a transition towards more sustainable energy systems

→ **Necessity for interdisciplinary study of socio-technical systems**

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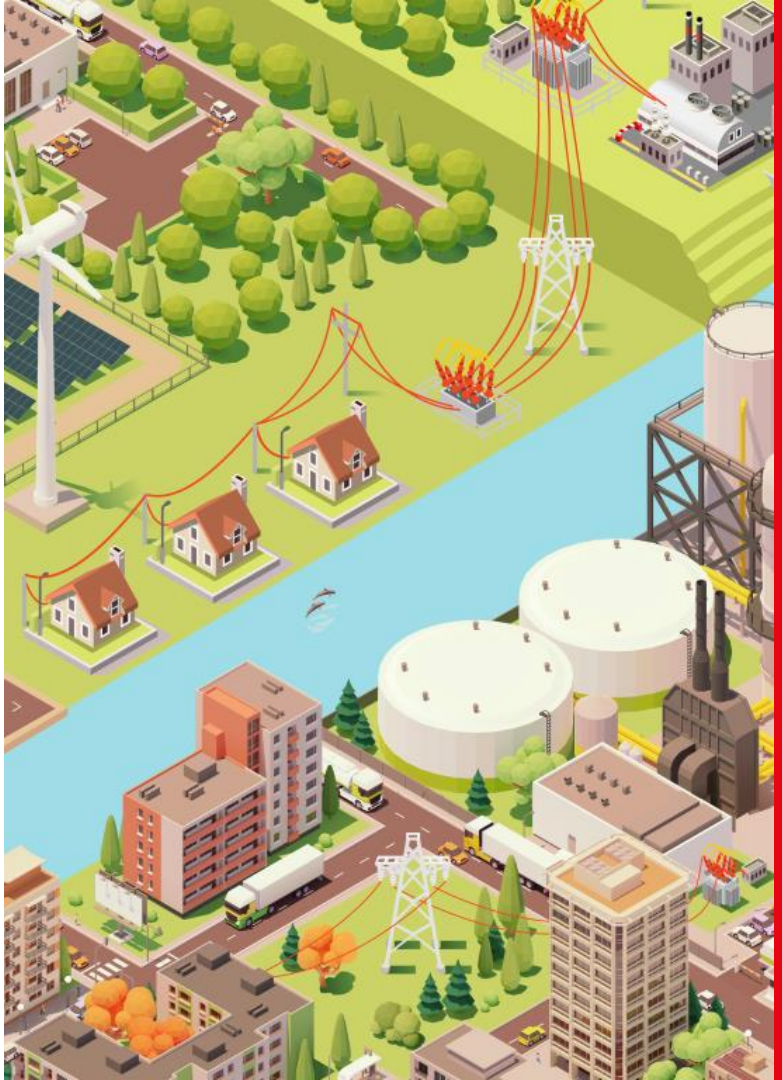

How can we study socio-technical systems (STS)?

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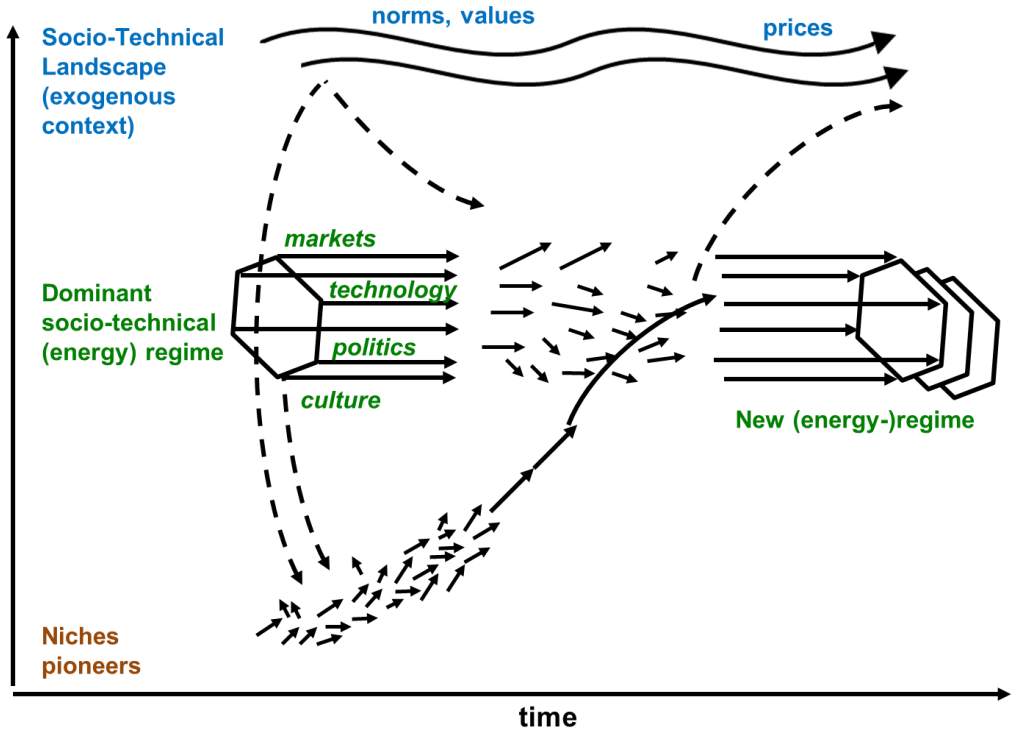
Multi-Level Perspective (MLP) of transitions



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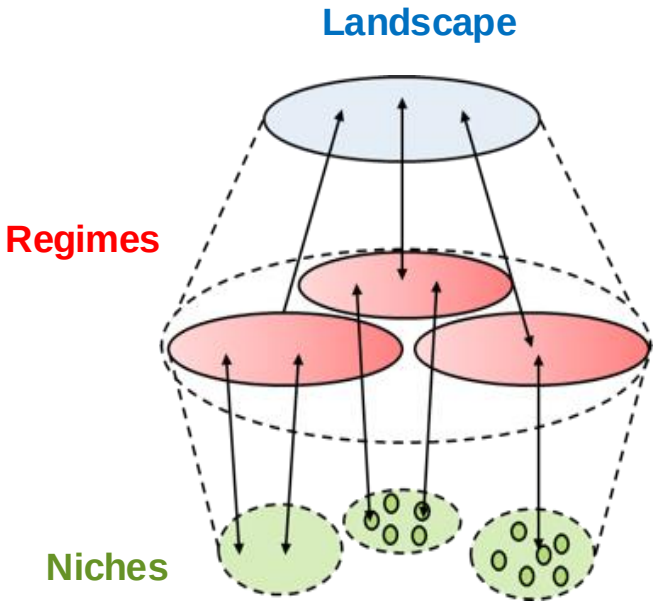
Sources: Geels, 2002; Geels and Schot, 2007

Multi-Level Perspective (MLP)



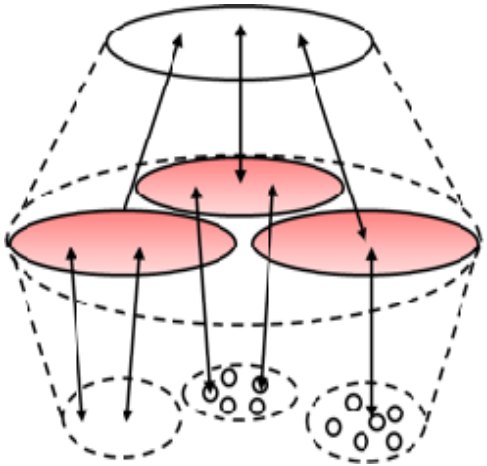
- Analytical tool that aims to clarify how transitions unfold
- Builds on:
  - Sociology & history of technology
  - Evolutionary economics
  - Institutional theory
- Distinguishes 3 analytical levels

Sources: Geels, 2002; Geels and Schot, 2007

Christophe Ballif / Philippe Thalmann / Claudia Binder

Regimes

Locked-in, path-dependent configurations developed in response to the needs of the past; once adapted, favor incremental innovation



Examples

Fossil-fuel-based mobility system
Gas-based energy system
MIND: Renewable based energy system

Regimes ≠ systems:
Regimes are constellations of rules that stabilize systems

Sources: Geels, 2002; Geels and Schot, 2007

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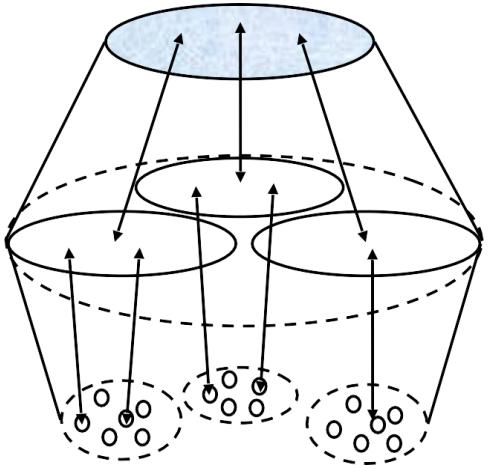
Landscape

Contextual factors that stabilize or put pressure on regimes



Examples
Climate change discourse
Population growth
Urbanization
Increasing oil prices
Financial crisis
Wars

Exogenous / autonomous trends and major crises, not easily changed:
Factors that do not change or change slowly: climate
Long-term developments: industrialization, urbanization
Rapid external shocks: wars, crisis, price fluctuations

Sources: Geels, 2002; Geels and Schot, 2007

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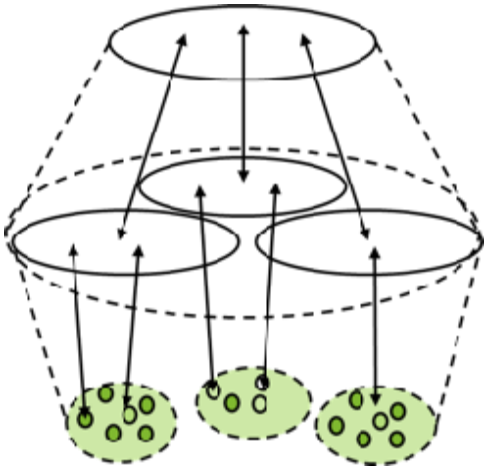
Niches

Alternatives to dominant practices, with potential to regime change, proto-regimes



Examples

Electric taxis in cities
PV systems in rural areas
Consumers as energy producers
Low-carbon lifestyles

Small-scale "spaces" - space for incubation of radical novelties:

Trying things out
Deviation from existing rules
Learning and building networks that support the novelties

Source: Geels, 2002; Geels and Schot, 2007

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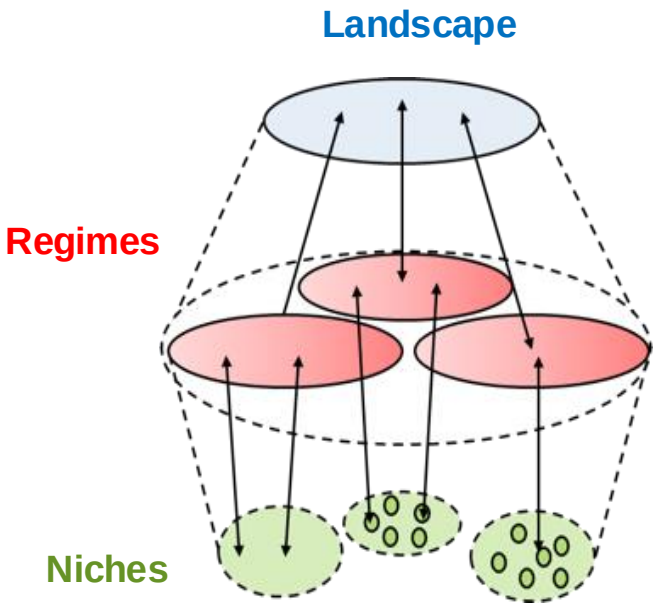
What types of transitions exist?



Sources: Geels, 2002; Geels and Schot, 2007

Types of transitions in MLP

Type of transition	Pressure landscape	Niche innovations	Outcome at regime level
Reproduction	None	No break trough	Stable regime
Transformation	Moderate	Starting to develop	Slow change of direction
Reconfiguration	Moderate	Radical innovations; combination of new and old technologies	New regime grows out of old regime
De-alignment & re-alignment	Divergent pressures	Multiple niche innovations	Destabilization with several technological options
Technological substitution	High	Highly developed innovations	New technical regime

Sources: Geels and Schot, 2008; Binder et al., 2019

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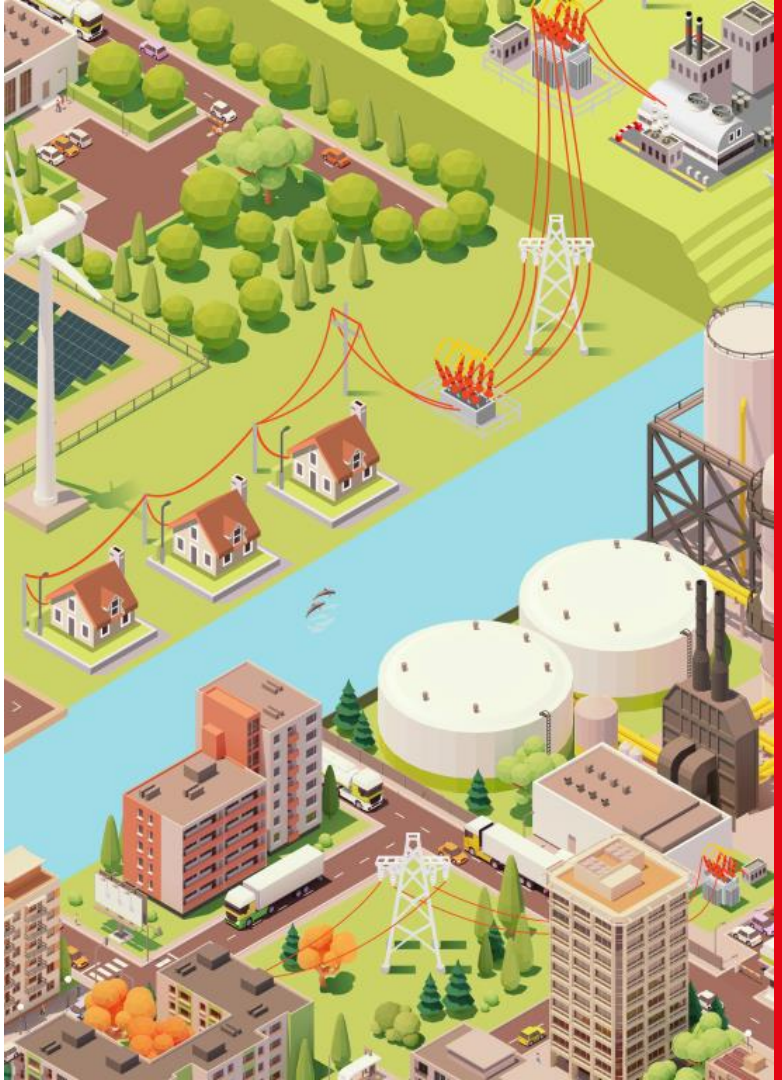

How can we analyze a transition?

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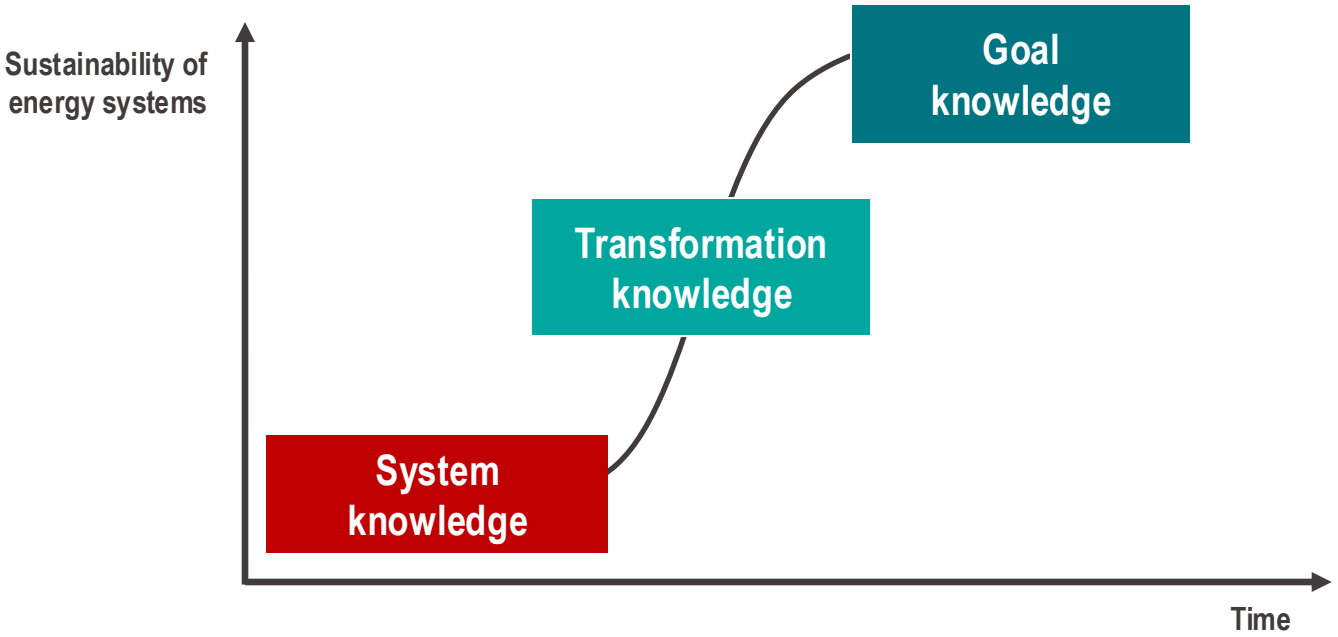
Three types of knowledge for transitions



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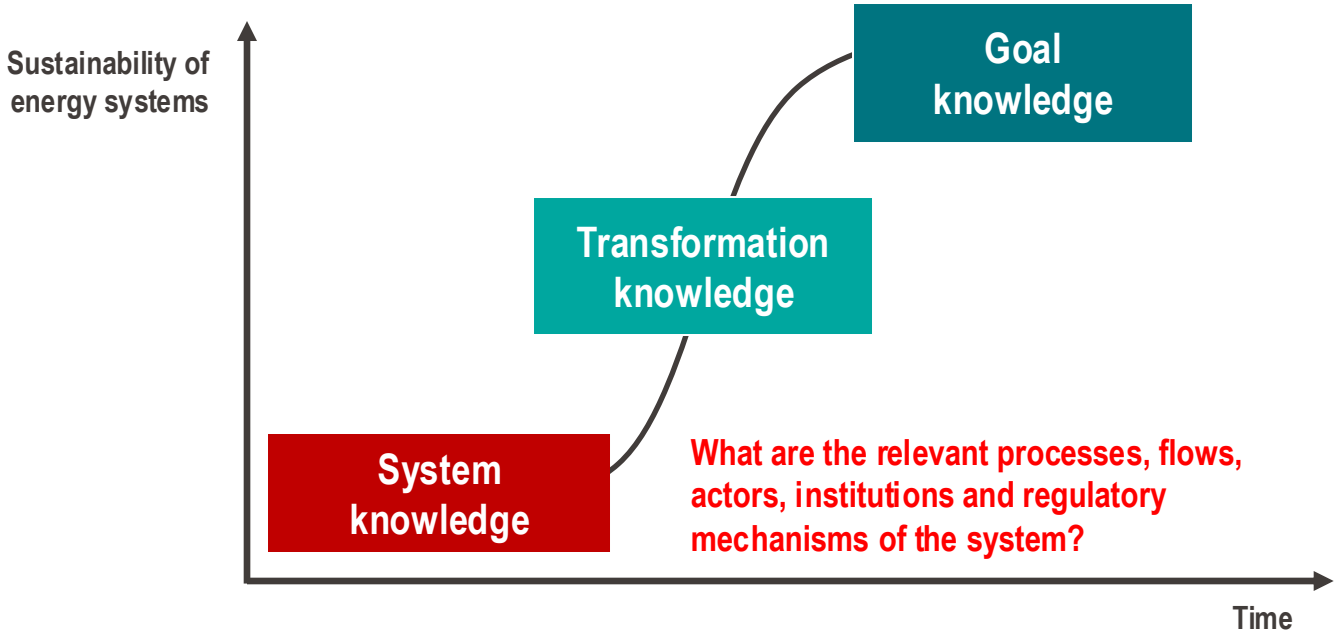
What questions do we ask?



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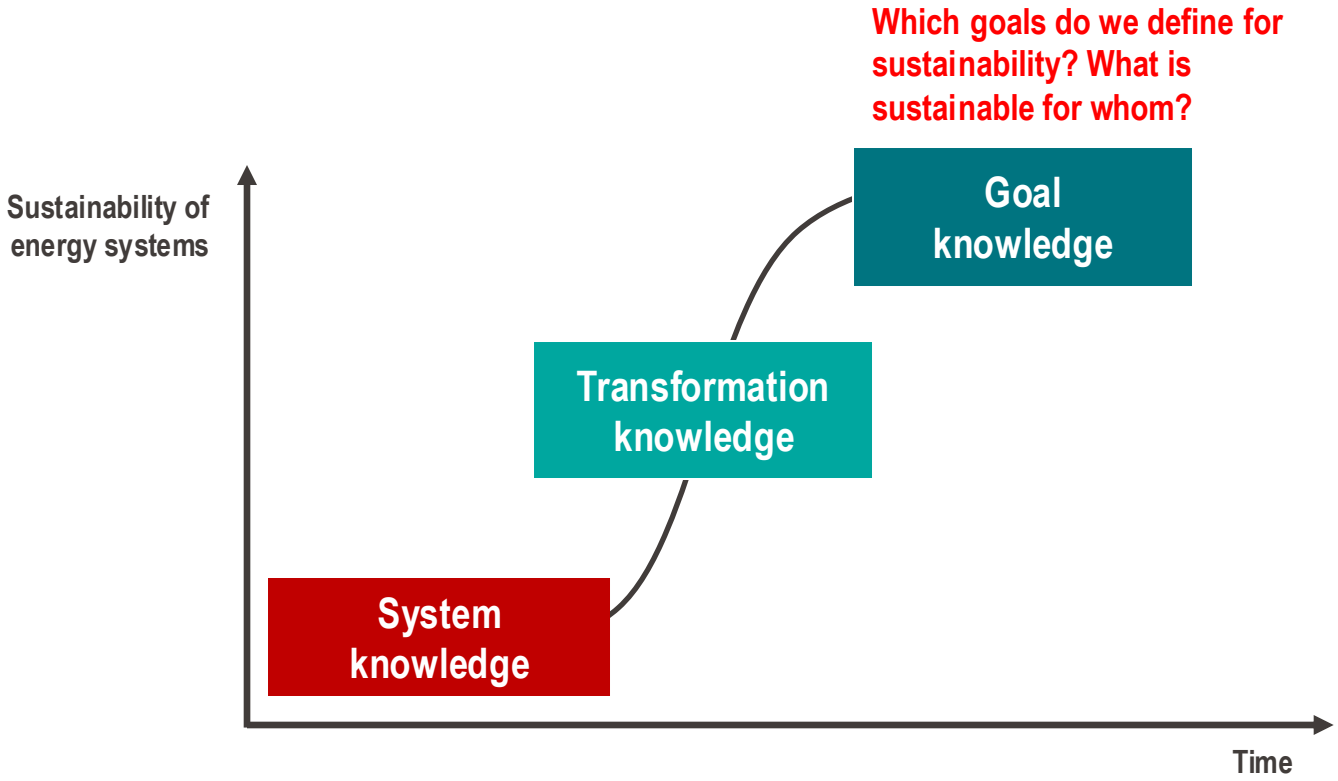

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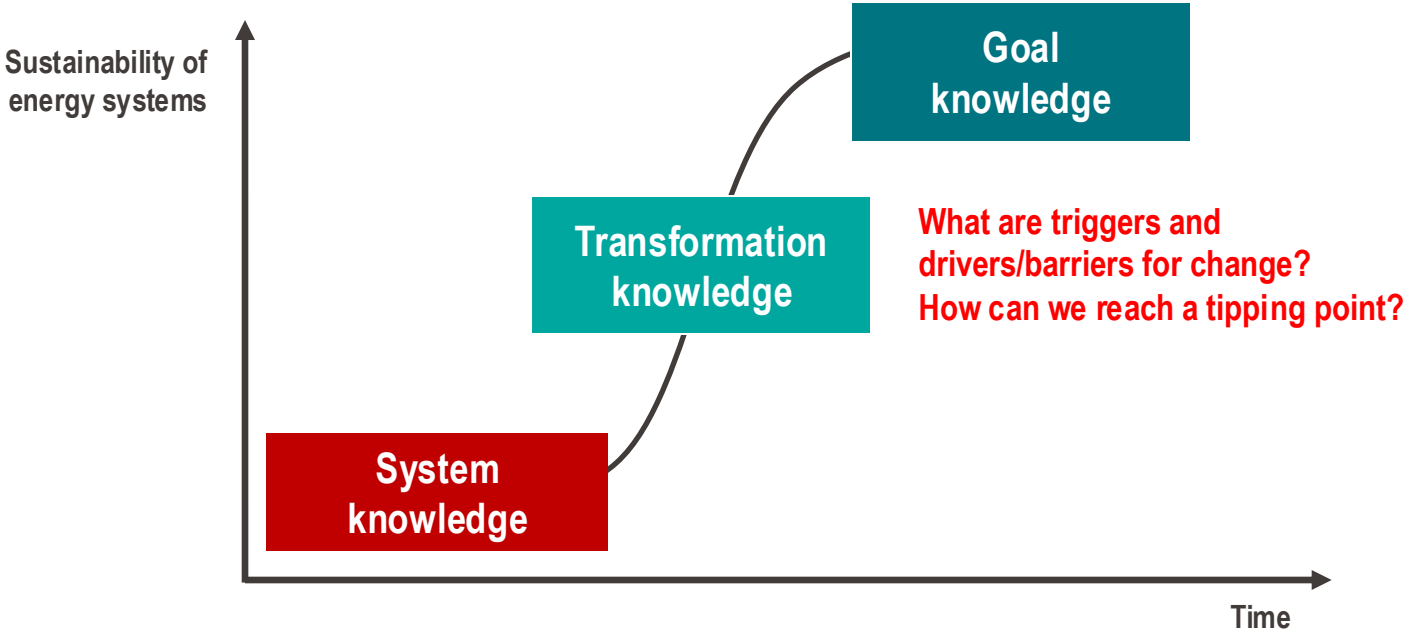

What are triggers and drivers/barriers for change?
How can we reach a tipping point?

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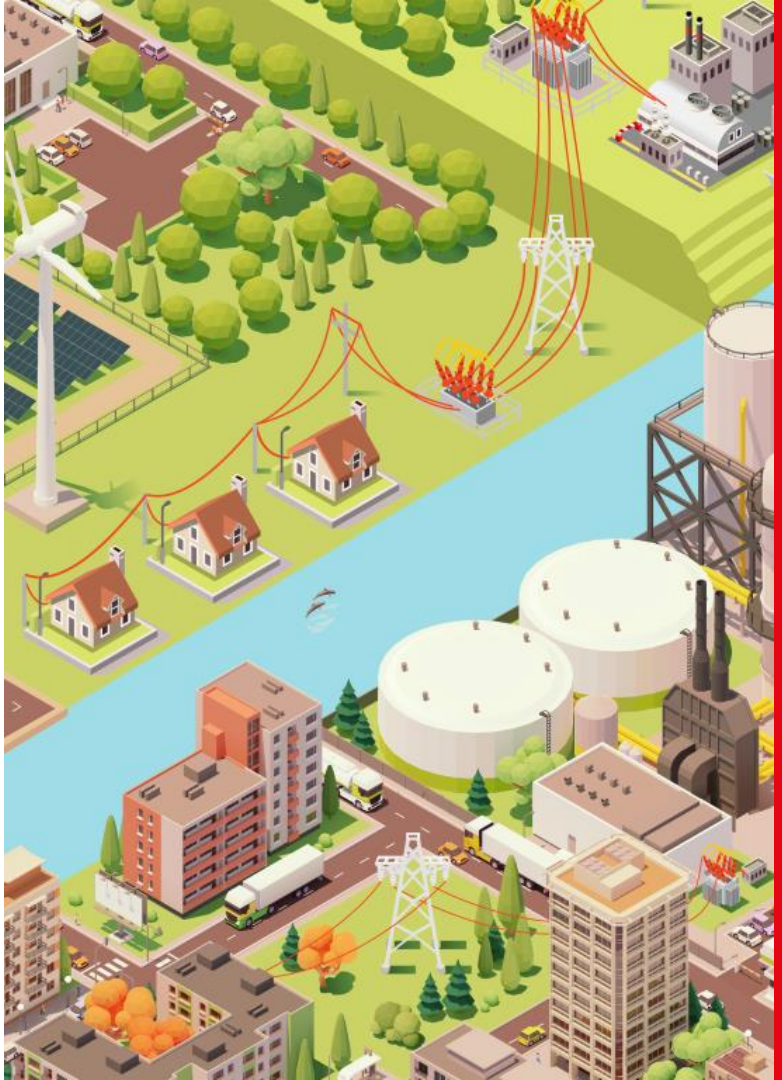

System knowledge

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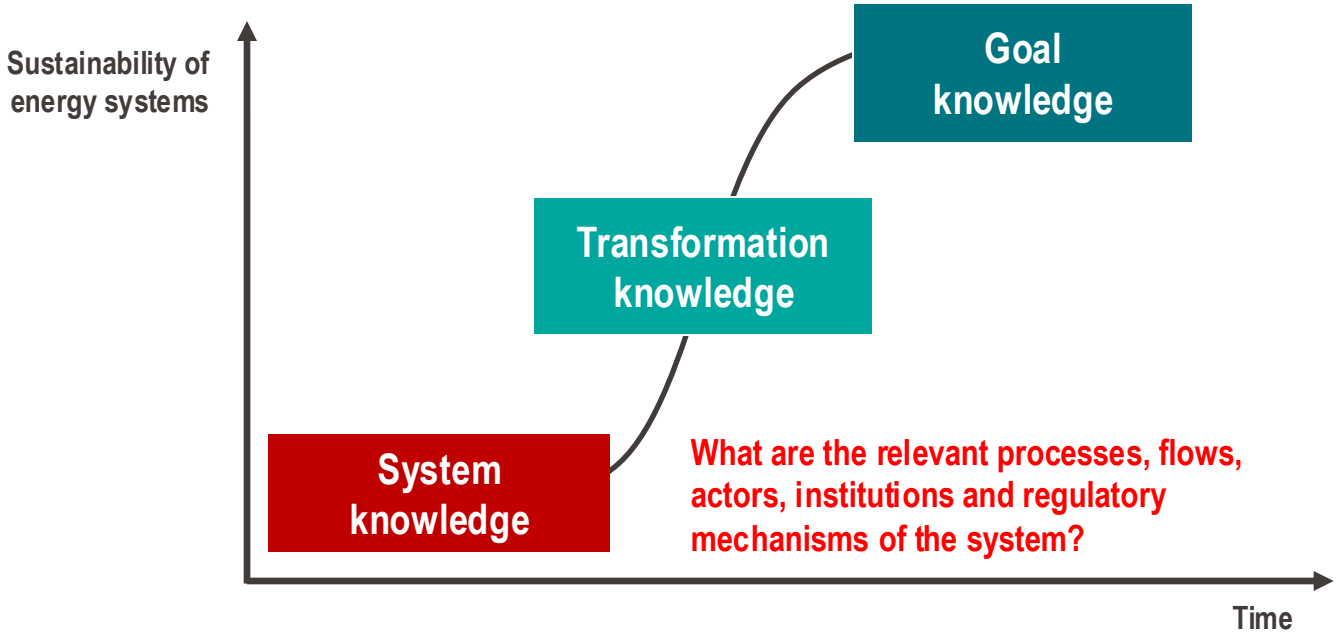
Three types of knowledge



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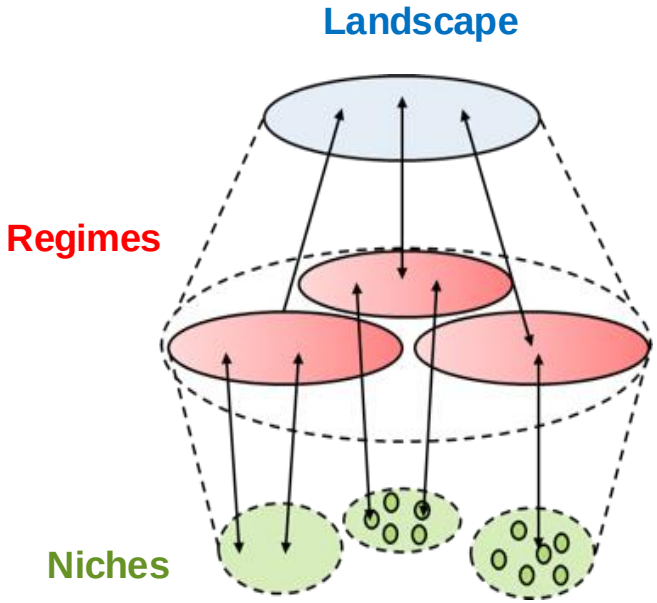
How can we depict this system?



Sources: Geels, 2002; Geels and Schot, 2007

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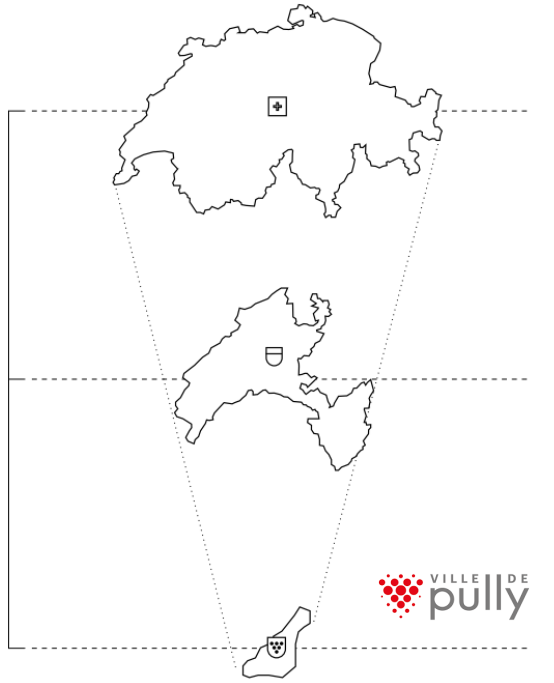
Characterization of the energy system in Pully

Technical
Social
Political
Socio-cultural



✚	Measured at the national level (Swiss Confederation Low-quality resolution)
⛉	Measured at the regional level (Canton of Vaud) Medium-quality resolution
⛉	Measured at the local level (City of Pully) Good-quality resolution

Sources: Campfens et al., 2023

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Energy system indicators

Regime, landscape and niche indicators?

Technical	Economic	Policy	Socio-cultural
Residential electricity demand	Electricity prices	Regulatory measures for solar PV	Perceived viability of solar PV by households
Residential heating demand	Feed-in remuneration from energy suppliers	Subsidies for solar PV	Desire for energy independence / self-sufficiency (autarchy)
Adoption of heat pumps	Fossil fuel prices		Active Peer effect / Social Influence

VILLE DE pully

Sources: Campfens et al., 2023

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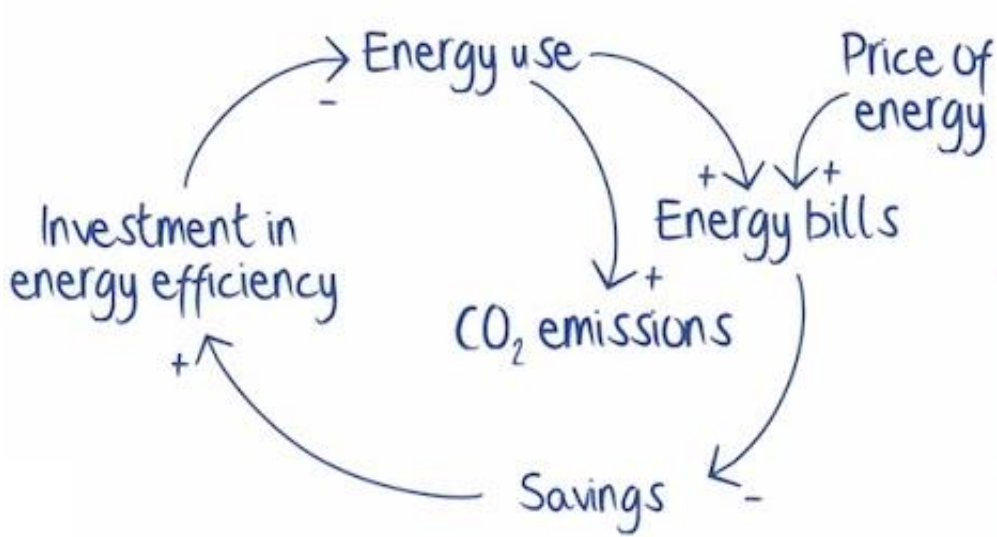
Developing a common understanding of the energy system in St. Prex



Commune de Saint-Prex

Sources: Campfens et al., 2023

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Developing a common understanding of the energy system in St. Prex

Sources: Campfens et al., 2023

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Niche developments: Local initiatives

SÉANCE D'INFORMATION

ROMANDE ENERGIE

canton de vaud

À VOUS DE JOUER !

Ensemble, vers une consommation d'énergie durable, autonome et intelligente.

[24] VAUD & RÉGIONS

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Accueil | Vaud & Régions | Nord vaudois-Broye | Patrimoine et énergie – Moudon, projet pilote pour le solaire en zone classée

Abo Patrimoine et énergie

Moudon, projet pilote pour le solaire en zone classée

Établi avec le Canton de Vaud, un guide pour le centre-ville permet d'intégrer des capteurs photovoltaïques en toiture.

Sébastien Galliker
Publié: 10.03.2022, 09h31

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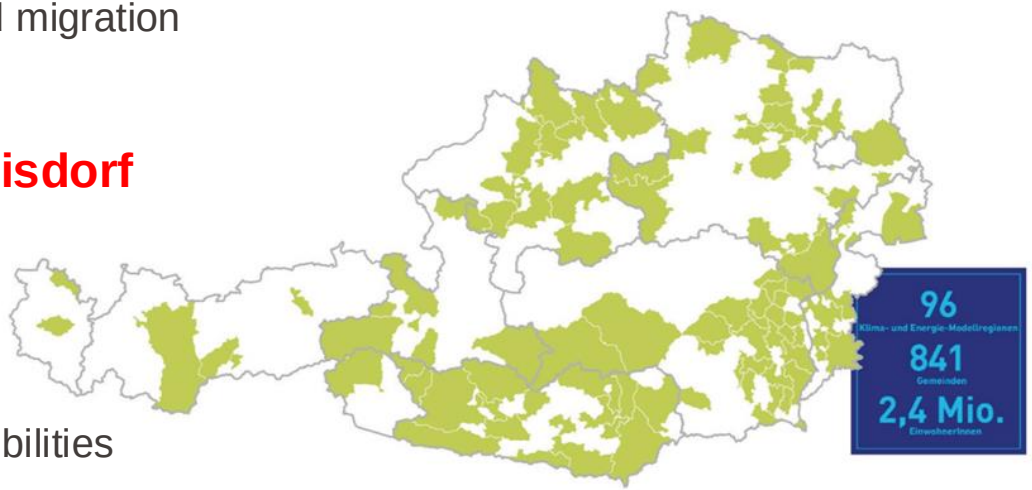
Güssing: Roots for the first energy region in AT

ökoEnergieland / Güssing

- Burgenland (AT)
- 14 communities
- Founded 1990 (2005)
- Biomass
- High unemployment and migration

Energy region Weiz-Gleisdorf

- Steiermark (AT)
- 18 communities
- Founded 1996
- Energy technologies
- Good employment possibilities



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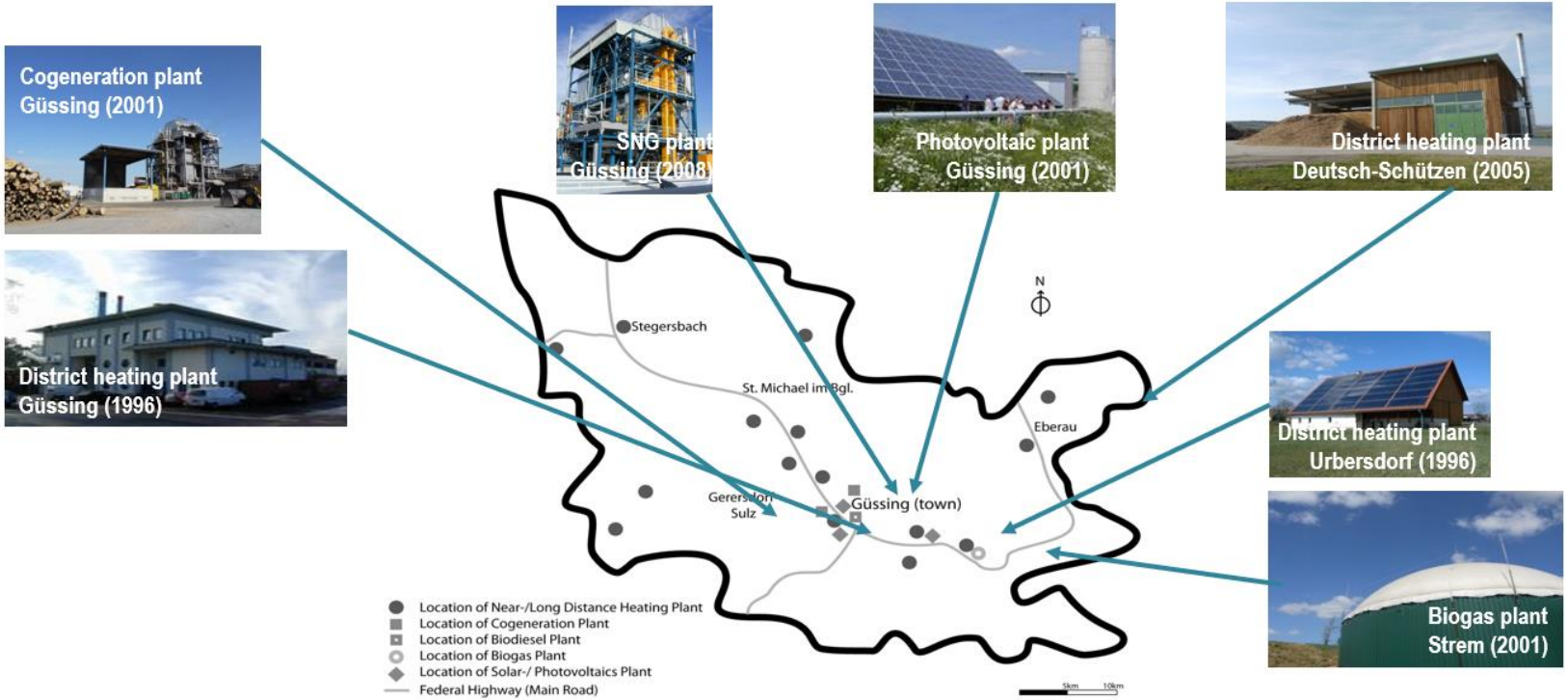
ökoEnergieland: Decentralized energy production



Source: Hecher, 2012; PSI, 2008

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Weiz-Gleisdorf: Light-house projects


Gemini house (2001)


Plus energy house (1997-2001)


Solar tree (1998)

Bike fueling station


Renovation district administration building (2010-11)

Source: Bedenik and Hecher, 2012

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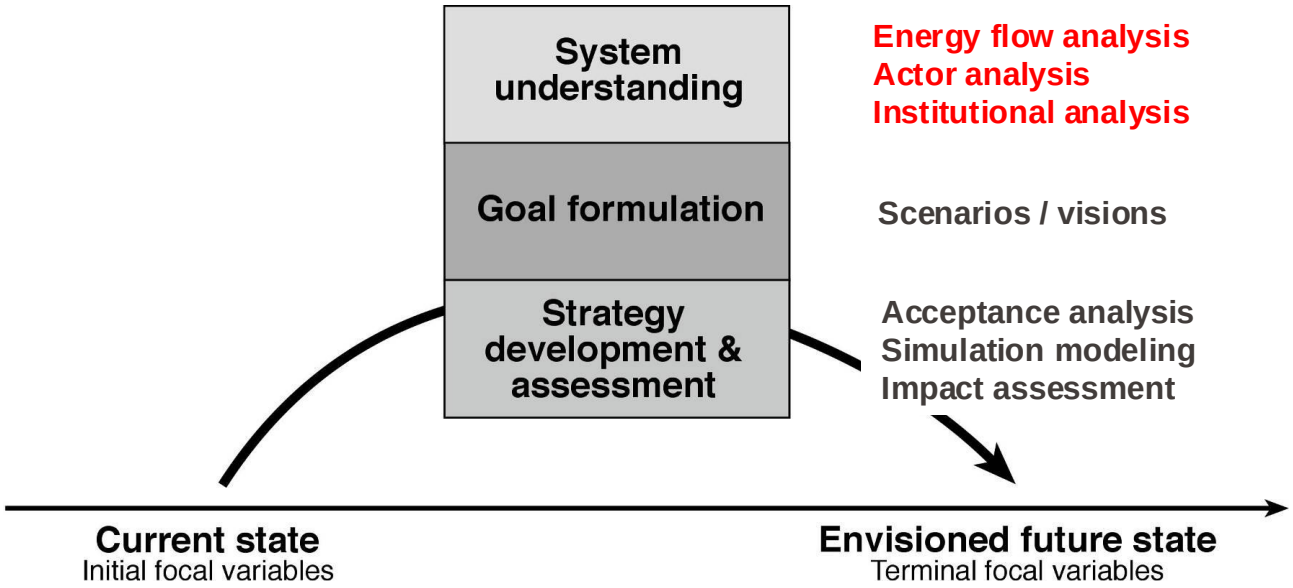
Elements of transition analysis



Source: Binder et al., 2004

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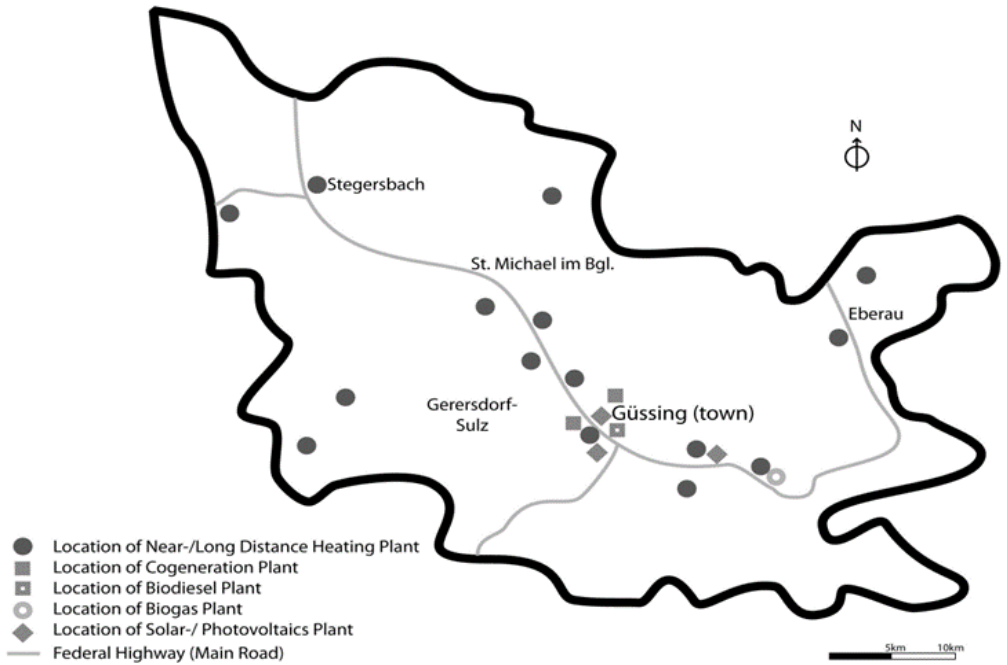
Which factors affected the transition of the energy region?



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Vision: Local leader ökoEnergieland

Ing. Reinhard Koch

- Basketball-National player (1985 -1992)
- Energy manager city Güssing (since 1989)
- Initiator Model Güssing (with mayor Vadasz) (ca. 1990)
- Foundation community heating Glasing (1991)
- Foundation community heating (1995)
- Co-founder and director of the European Center for Renewable Energy (since1996)
- Manager of the year (2008) (Burgenland)
- Schweighofer price (2009)
- Regional energy manager (since 2010)

Vision: Weiz-Gleisdorf

1990er: „Dass man sich überlegt hat, welche Gemeinden können überhaupt kooperieren und dann gemeinsam etwas zu machen.“(Hierz, 2011)

„We started thinking which communities could cooperate with each other to do something together.“

1995: „Wir brauchen ein gemeinsames Miteinander dann haben wir eine Chance dass wir Finanzmittel leichter bekommen.“ (Kern, 2011)

„We need to work together, that we have the chance to receive funding more easily.“

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Milestones in the energy transition

Milestones	Definition	*Examples ökoEnergieland*
Visionary	Densification of guiding ideas	*Energy Charta*
Institutional	Permanent and binding agreements of varying degrees	*Foundation of "ökoEnergieland"*
Physical	Infrastructural measures in the energy sector	*SNG-plant; district heating plants*
External	Events affecting the development from outside	*Joining EU; Leader funding program at EU level*

Sources: Hecher, et al. 2016; Binder et al., 2014

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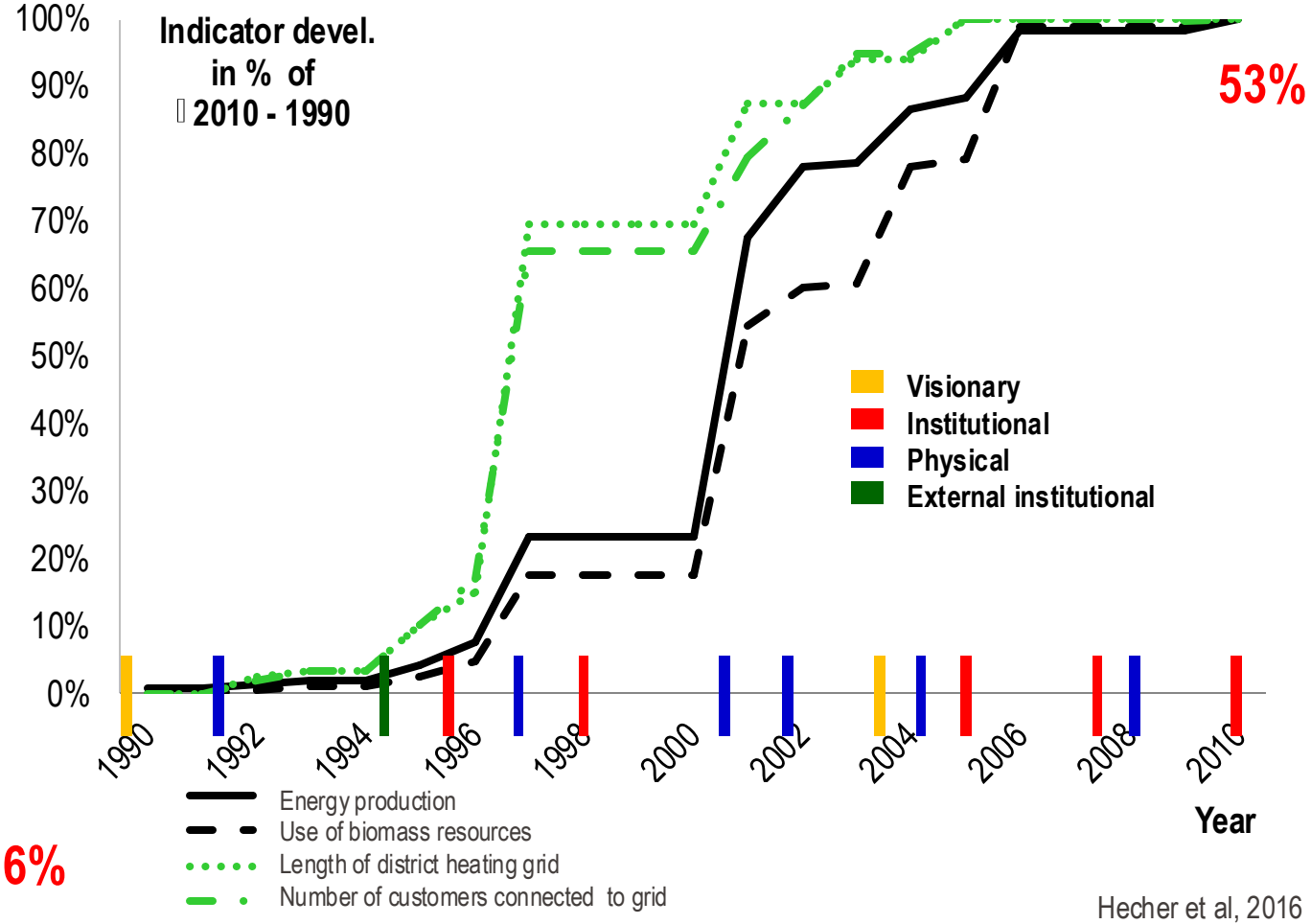
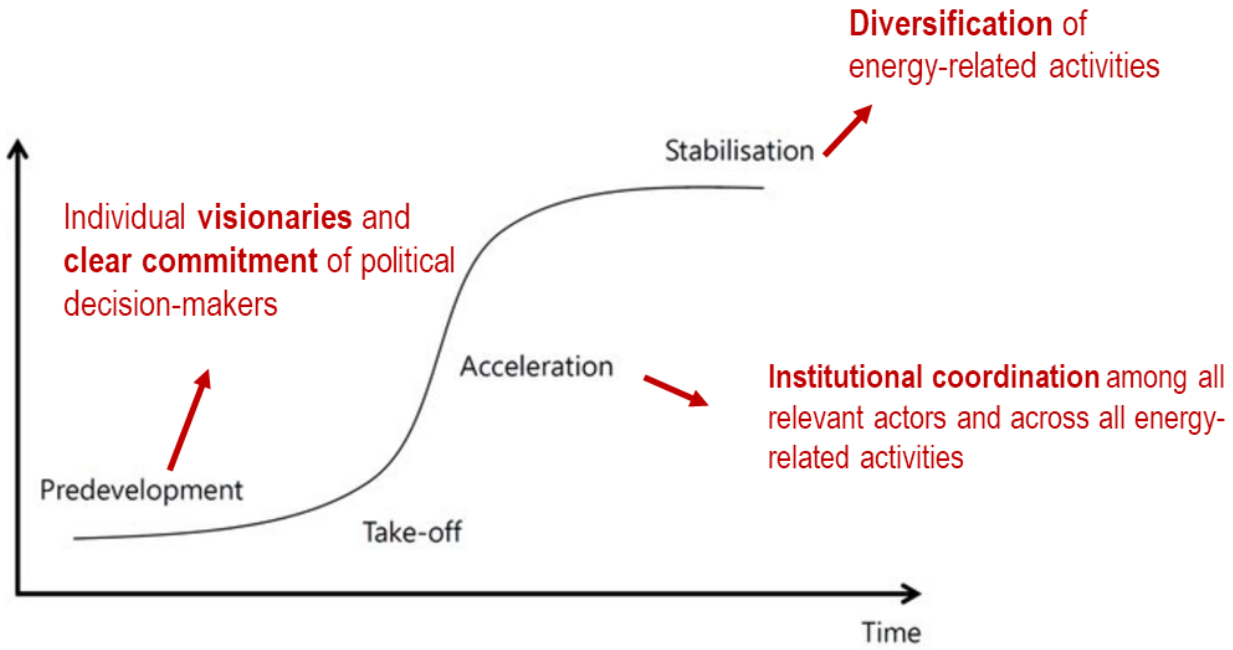


Hecher et al, 2016

ökoEnergieland: Actor and institutional analysis



Source: Hecher et al. 2016

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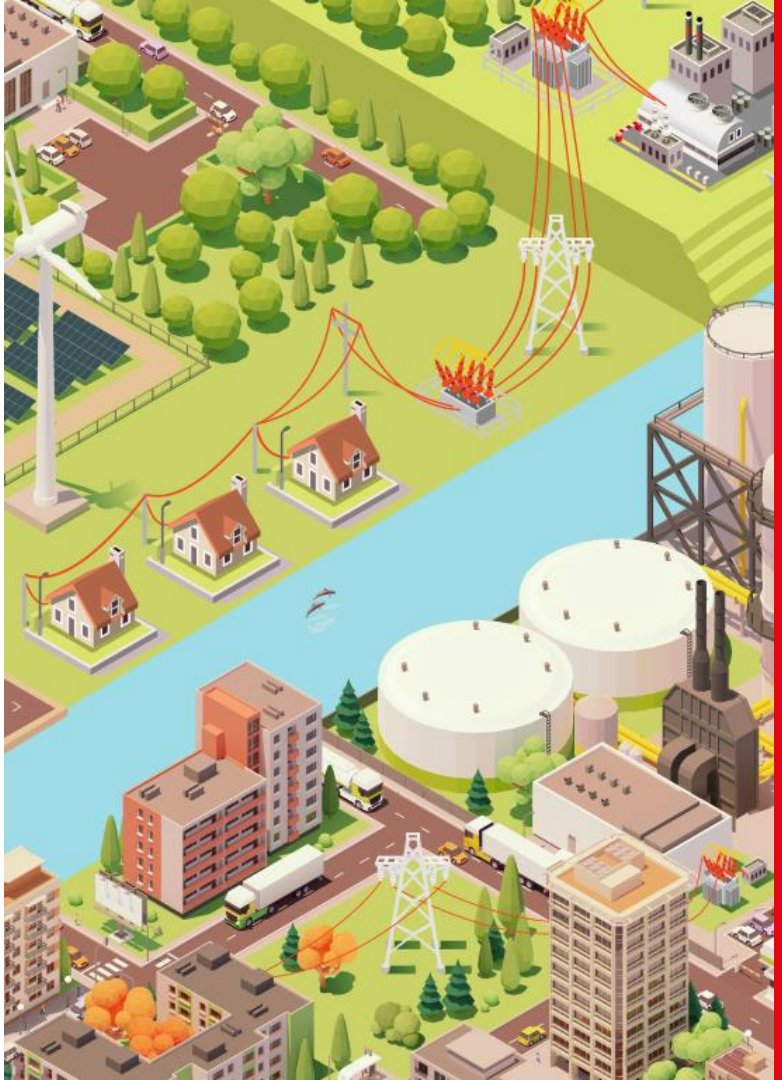
First learnings from the energy transition

- **Individual visionary** people are key drivers of the transition
- **Co-evolution of social-ecological-technical systems (SETs):** Visionary and institutional milestones precede physical ones
- **External "events"** can fuel the transition



Goal knowledge

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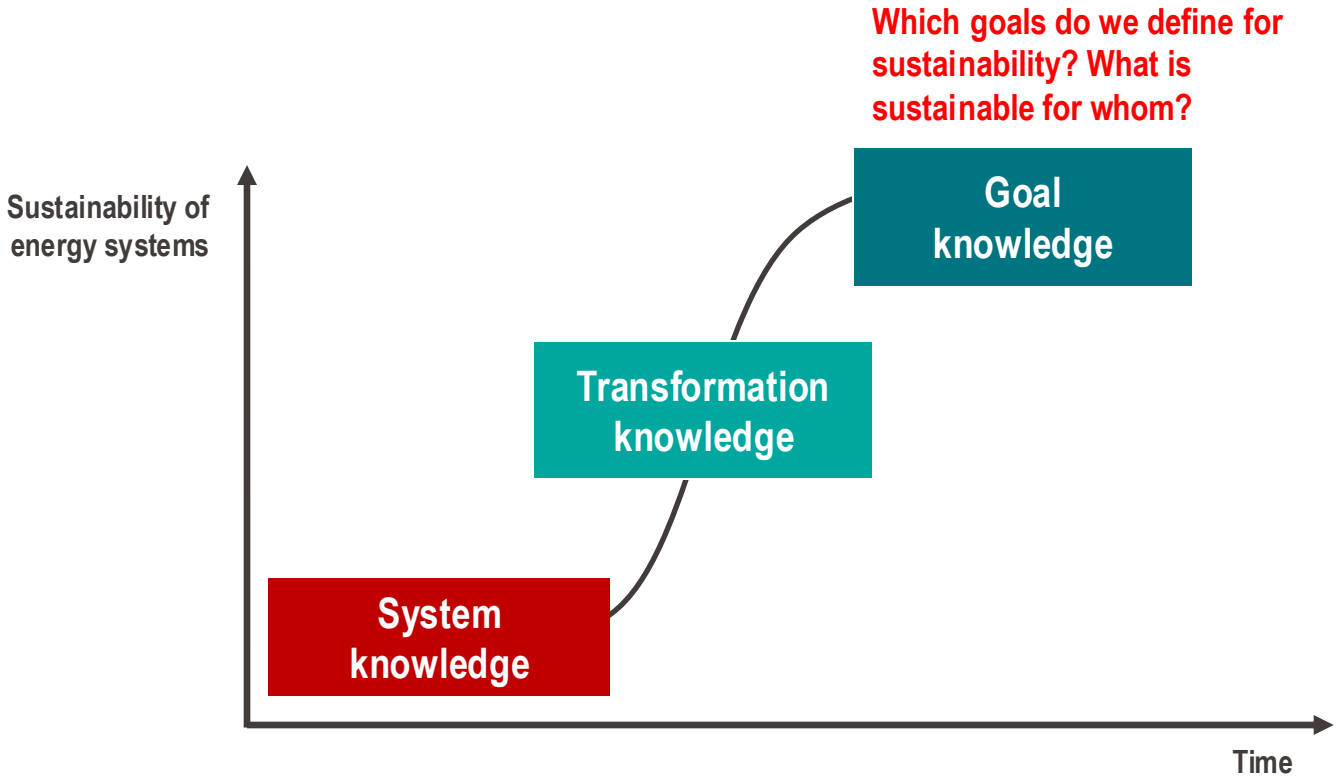
What questions do we ask?



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Sustainable Development Goals (SGDs) 2030

Source: sustainabledevelopment.un.org/sdg7

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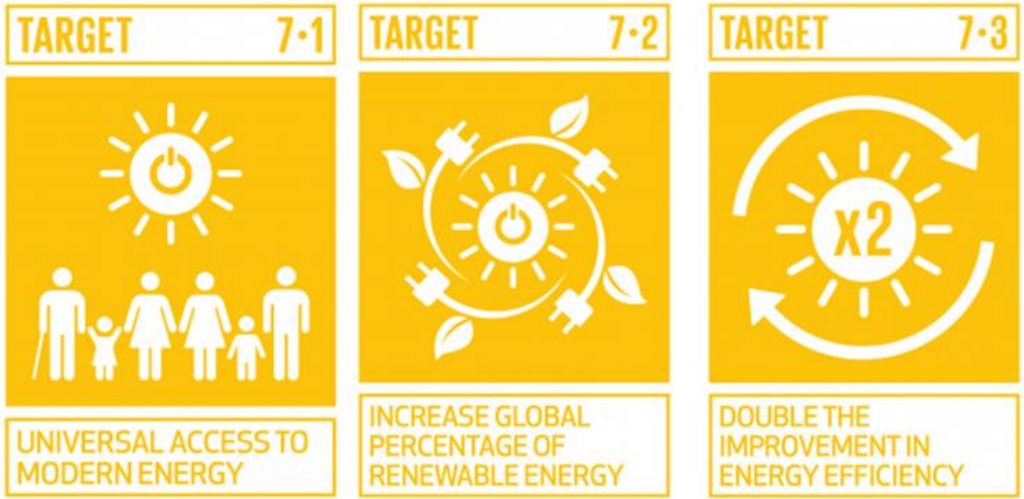
SDG targets are relatively vague



Source: sustainabledevelopment.un.org/sdg7

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SDG targets are relatively vague

7.1 Ensure universal access to affordable, reliable and modern energy services

- Indicator 7.1.1 Percentage of the population with access to electricity
- Indicator 7.1.2 Proportion of population with primary reliance on clean fuels and technology

7.2 Increase substantially the share of renewable energy in the global energy mix

- Indicator 7.2.1 Renewable energy share in the total final energy consumption

7.3 Double the global rate of improvement in energy efficiency

- Indicator 7.3.1 Energy intensity measured in terms of primary energy and GDP

Source: sustainabledevelopment.un.org/sdg7

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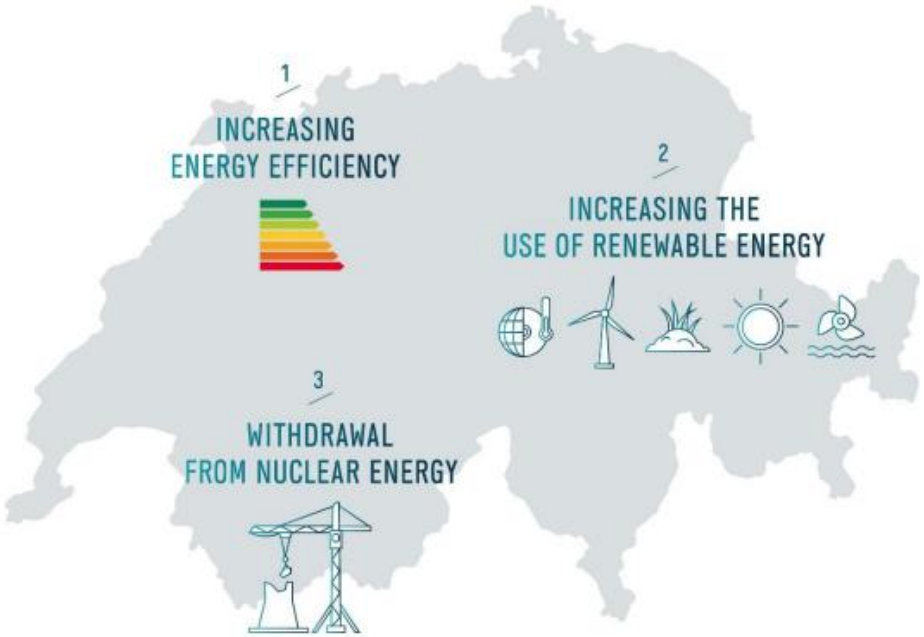
Swiss Energy Strategy 2050: Three strategic objectives



Source: SFOE, 2018

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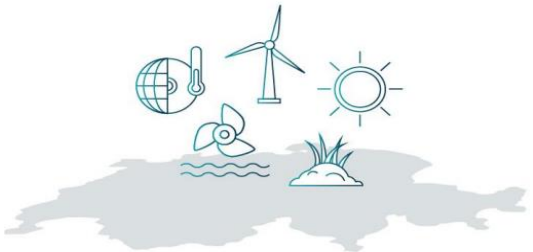
Swiss Energy Strategy 2050

Average energy consumption per person compared to 2000

- Until 2035: minus 43%
- Until 2050: minus 53%



Electricity consumption compared to 2000

- Until 2035: minus 3%
- Until 2050: minus 5%

Electricity production with renewables

- Until 2035: 17 TWh
- Until 2050: 39 TWh

Source: BFE, 2021

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Energy consumption of HH in PJ/year

Energy carrier	2000	2017	2021	Δ'00-'21
Electricity	56.6	69.2	72.5	+28.0%
Fossil fuels	**153.0**	**124.8**	**129.0**	**-15.7%**
Oil	116.5	76.2	66.1	
Gas	36.4	48.5	53.2	
Coal	0.1	0.1	0.1	
District heating	4.8	7.7	9.6	+100%
Wood	18.0	19.4	19.8	+9.8%
Other renewables	3.9	15.5	19.9	+411.6%
Sum	**236.3**	**236.5**	**241.2**	**+2.0%**

Source: BFE, 2022

Lausanne: Energy goals at regional level

2 objectifs dans 3 domaines:

Mobilité: zéro émission directe dès 2030, donc 0 véhicule thermique à cette date sur sol lausannois.

Bâtiments et **traitement des déchets** et de **l'eau:** zéro émission directe en 2050

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Pully: Energy goals at the regional level

Target	Technical	Economic	Policy	Socio-cultural
Residential solar PV deployment	Residential electricity demand	Electricity prices	Regulatory measures for solar PV	Perceived viability of solar PV by households
Household energy consumption	Residential heating demand	Feed-in remuneration from energy suppliers	Subsidies for solar PV	Desire for energy independence / self-sufficiency (autarchy)
GHG emissions	Adoption of heat pumps	Fossil fuel prices		Active Peer effect / Social Influence

VILLE DE pully

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Some insights from goal knowledge

- **Diverse, sometimes unspecific goals**
- **Complex system(s)**
  - Spatial and temporal scales
  - Interaction between technical and social systems
    - Diversity of goals for technologies emerging at different pace
    - Diversity of goals because of actors and their interests
  - Transition pathways are unclear

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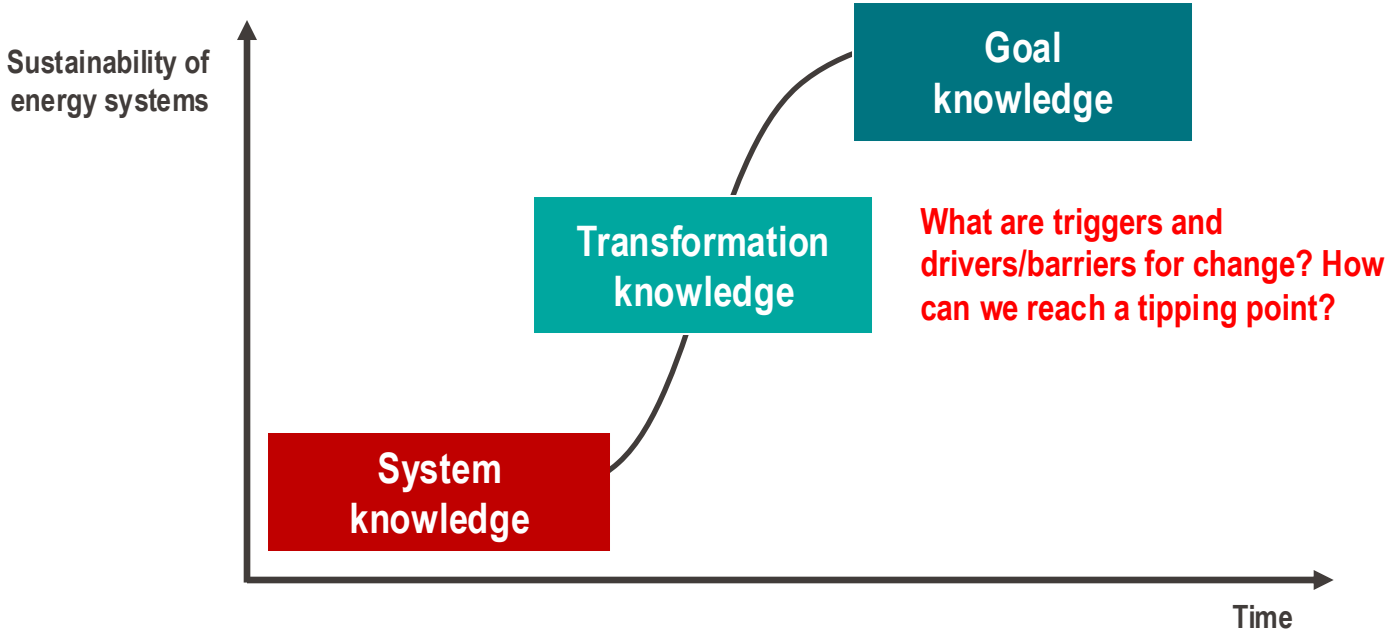
Transformation knowledge

Tipping points

What questions do we ask?



What are triggers and drivers/barriers for change? How can we reach a tipping point?

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Definition of tipping points

- Point or threshold at which **small quantitative changes** in the system trigger **a non-linear change process** that is driven by system-internal feedback mechanisms and inevitably leads to a **qualitatively different state** of the system, which is often **irreversible**.

- The structure and the dynamics of the system change. This new state can be distinguished from the original by its **fundamentally altered** positive or negative **state-stabilizing feedbacks**.

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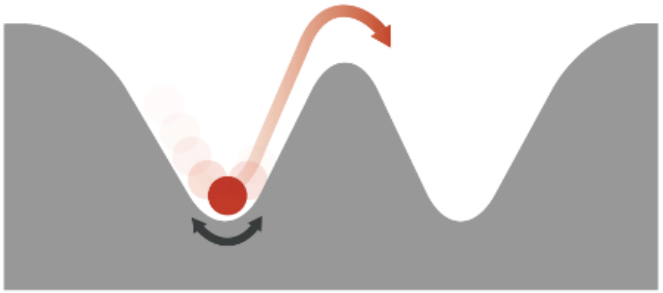
Sources: Milkoreit et al. 2018; Spaiser et al. 2018

Tipping points in ecological systems

A resilient system returns to equilibrium quickly after a small push (**black**). It takes a major push (**red**) to tip the system into a new stable state.



A less resilient system recovers more slowly from small pushes (**black**). This "critical slowing down" can be a warning sign that the system could easily tip into a new state (**red**).

Sources: Scheffer et al. 2009; Popkin 2014

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Social tipping points

The tipping point for social change is precise: 25%.

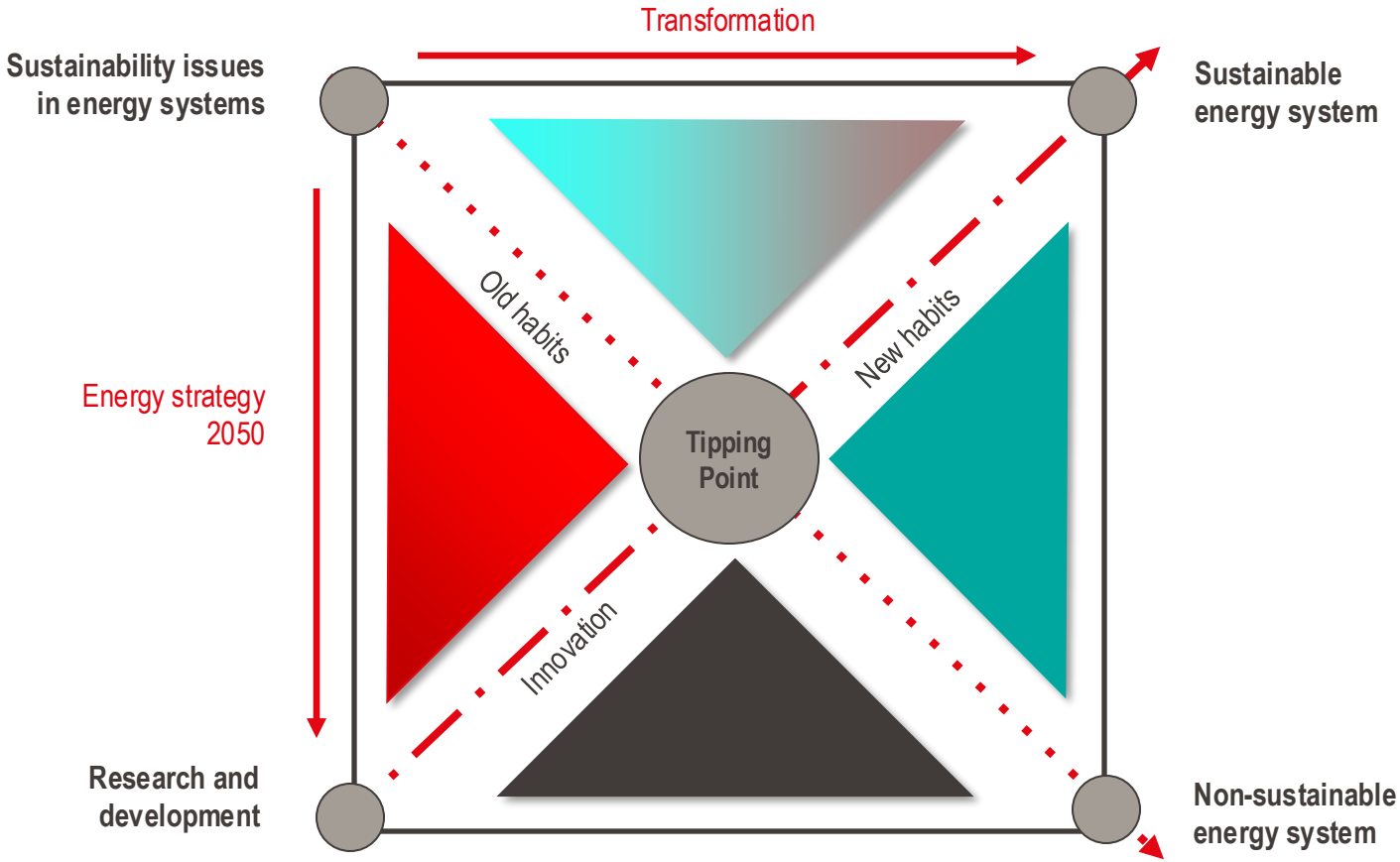
Social scientist Damon Centola's new research shows a cascade of change is triggered when 25% of a population embraces an idea. Minority views of what is acceptable

"Social tipping points are desirable and necessary to address a range of sustainability challenges."

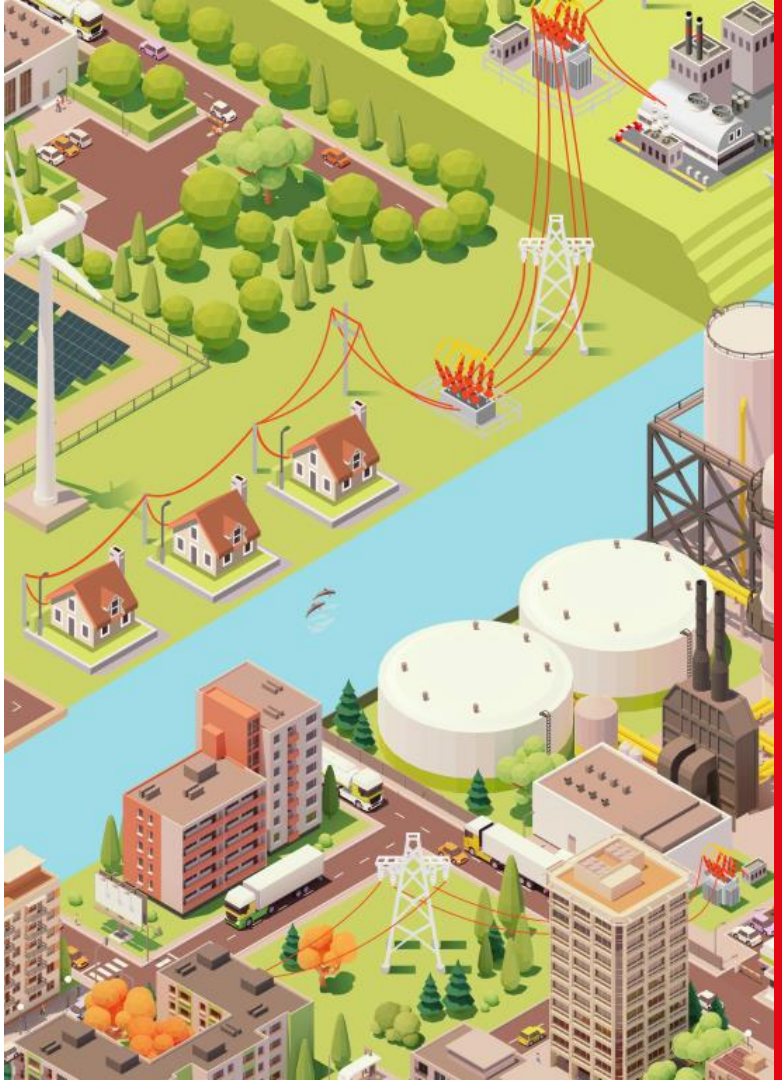
Westley et al., 2011

Source: Centola, 2021

Thinking of tipping points



Source: Binder, 2018



Transformation knowledge

Transition pathways

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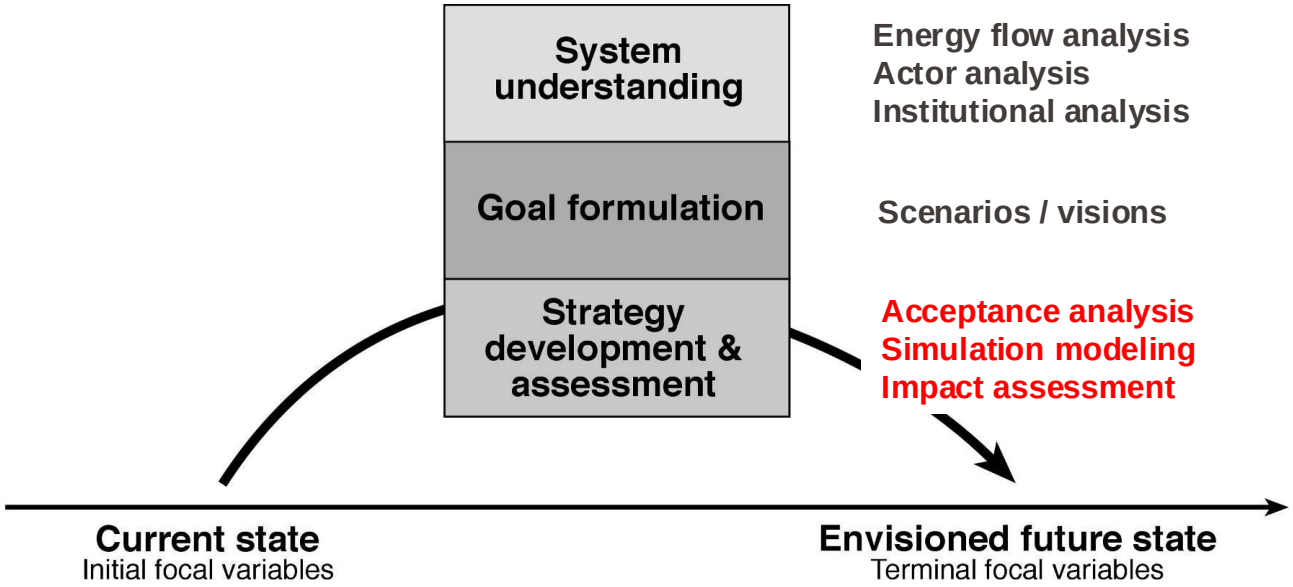
Elements of transition analysis



Source: Binder et al., 2004

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Building model Weiz-Gleisdorf: Conceptual approach

Scenarios for regional energy demand

Bottom up simulation of 15 scenarios
- Envelope renovation rate
- Legislative standards
- Heating technologies

Entities
- Individual buildings (SFH, MFH, NRB)
- Construction period
- Heating system

Data source
- Statistical office Austria

Regional supply of renewable energy

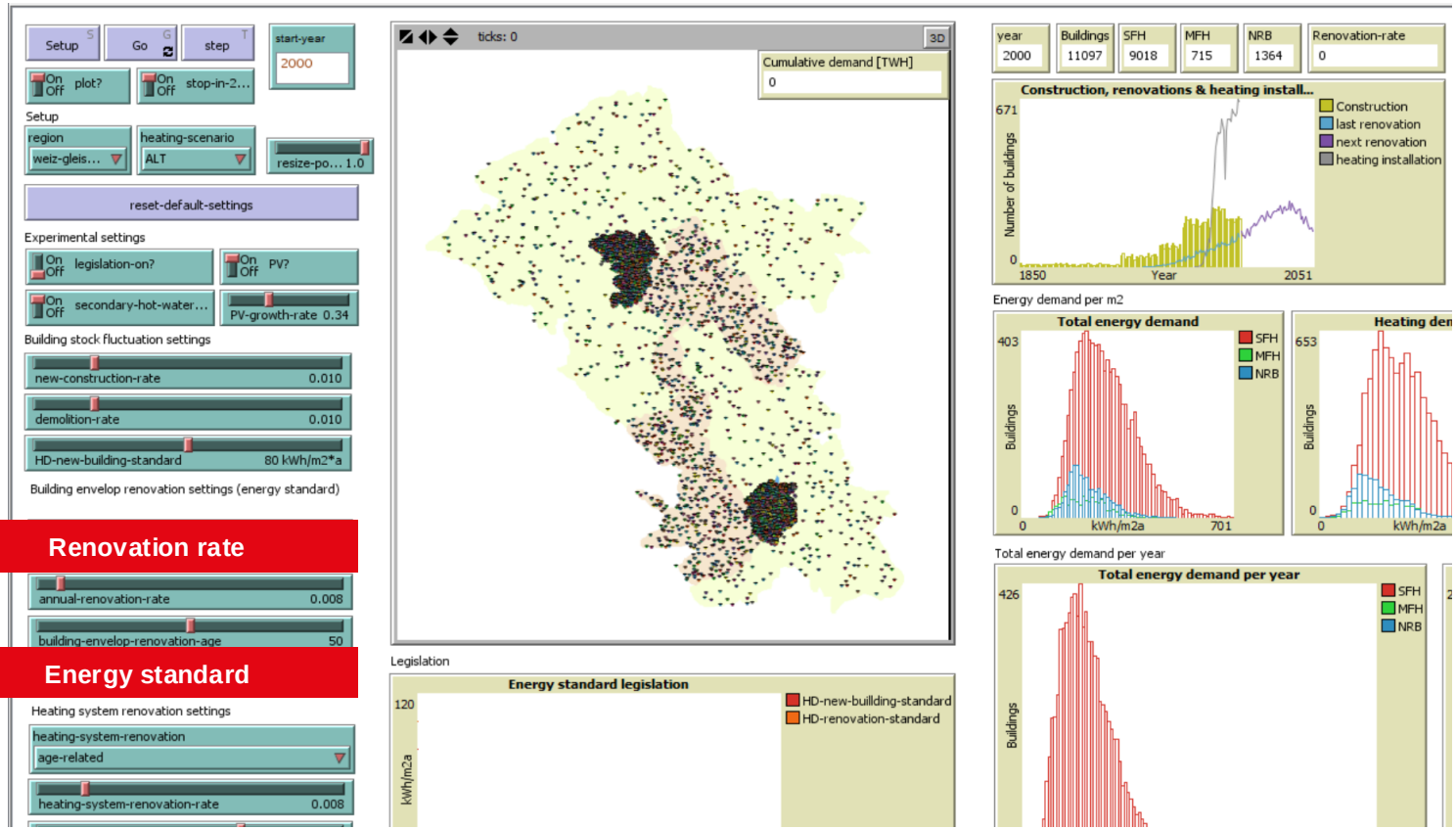
Top down scenarios for supply potential
- Technical maximum
- Competing use
- Spatial accessibility

Entities
- Forest
- Agriculture
- Solar energy (PV, solar-thermal)

Data source
- Statistical office Austria

Source: Binder et al., 2016

Simulating if-then scenarios



Source: Binder et al. 2016

Energy standards and energy demand in 2050

BAU

Ren. rate: 0.8%

Energy standards

New B.: 80 kWh/m²a

Ren. B.: 100 kWh/m²a

REN

Ren. rate: 1.6%

Energy standards

New B.: 80 kWh/m²a

Ren. B.: 100 kWh/m²a

LEG

Ren. rate: 0.8%

Energy standards

New B.: 25 kWh/m²a

Ren. B.: 50 kWh/m²a

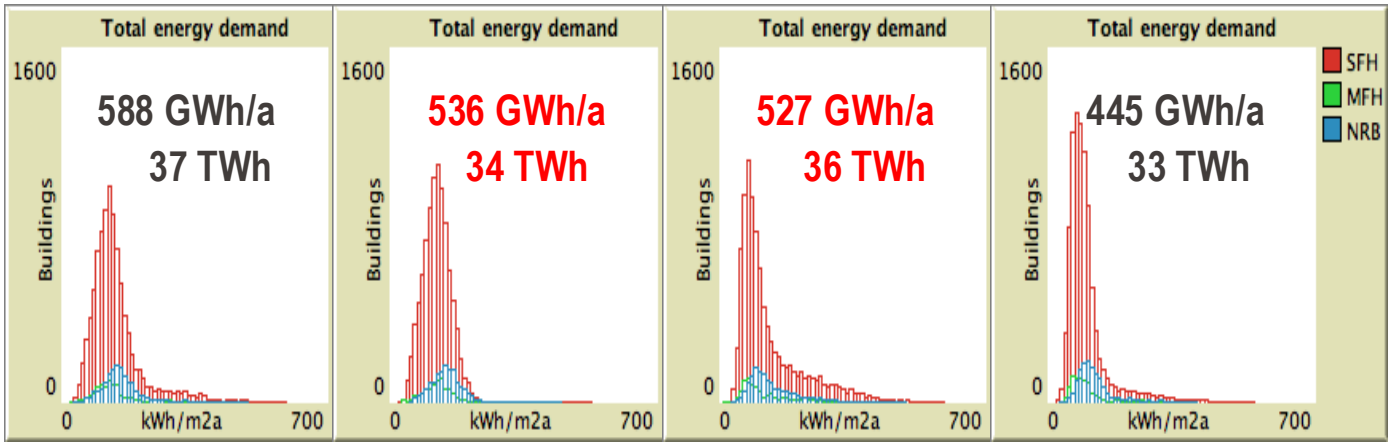
TRANS

Ren. rate: 1.6%

Energy standards

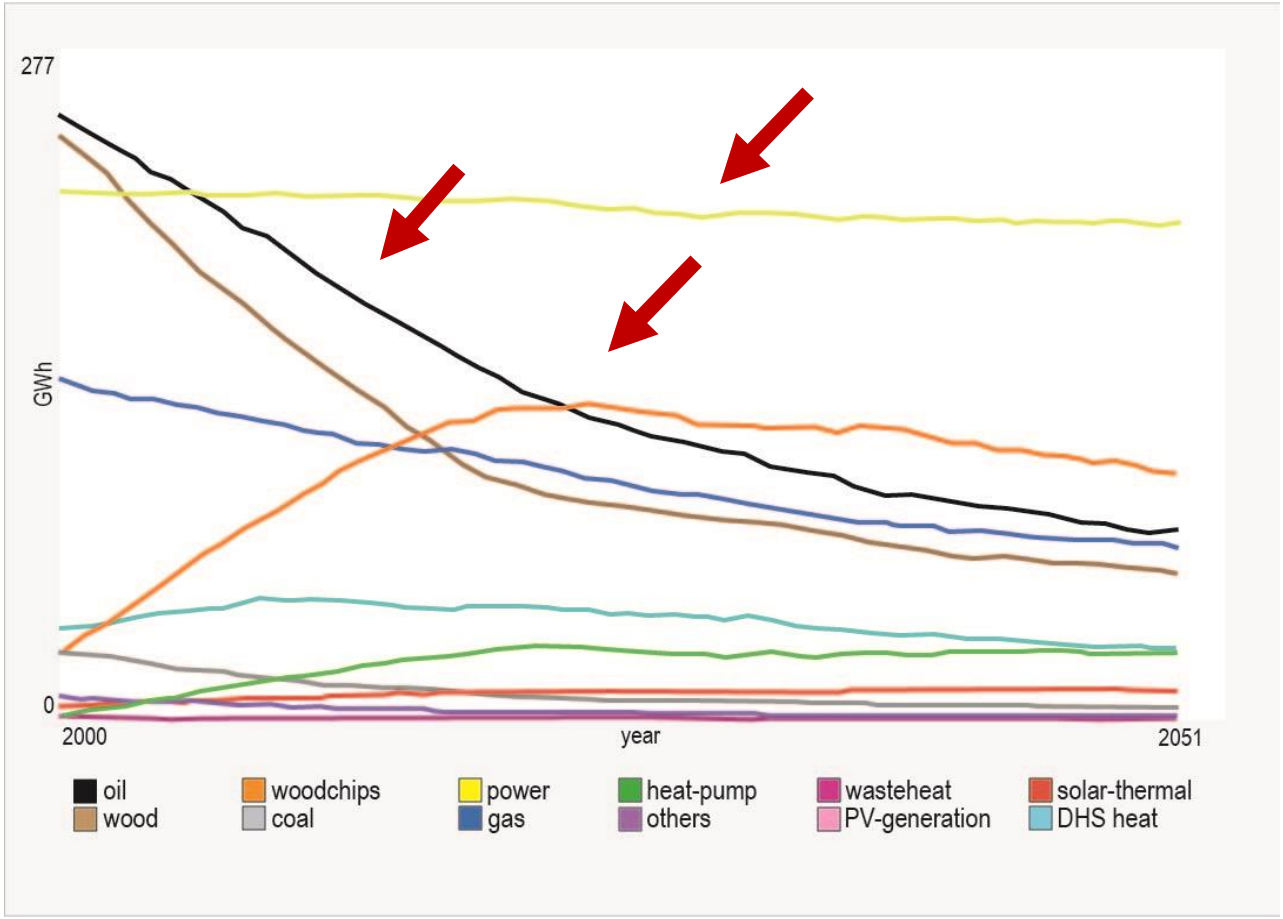
New B.: 25 kWh/m²a

Ren. B.: 50 kWh/m²a



Binder et al., 2016

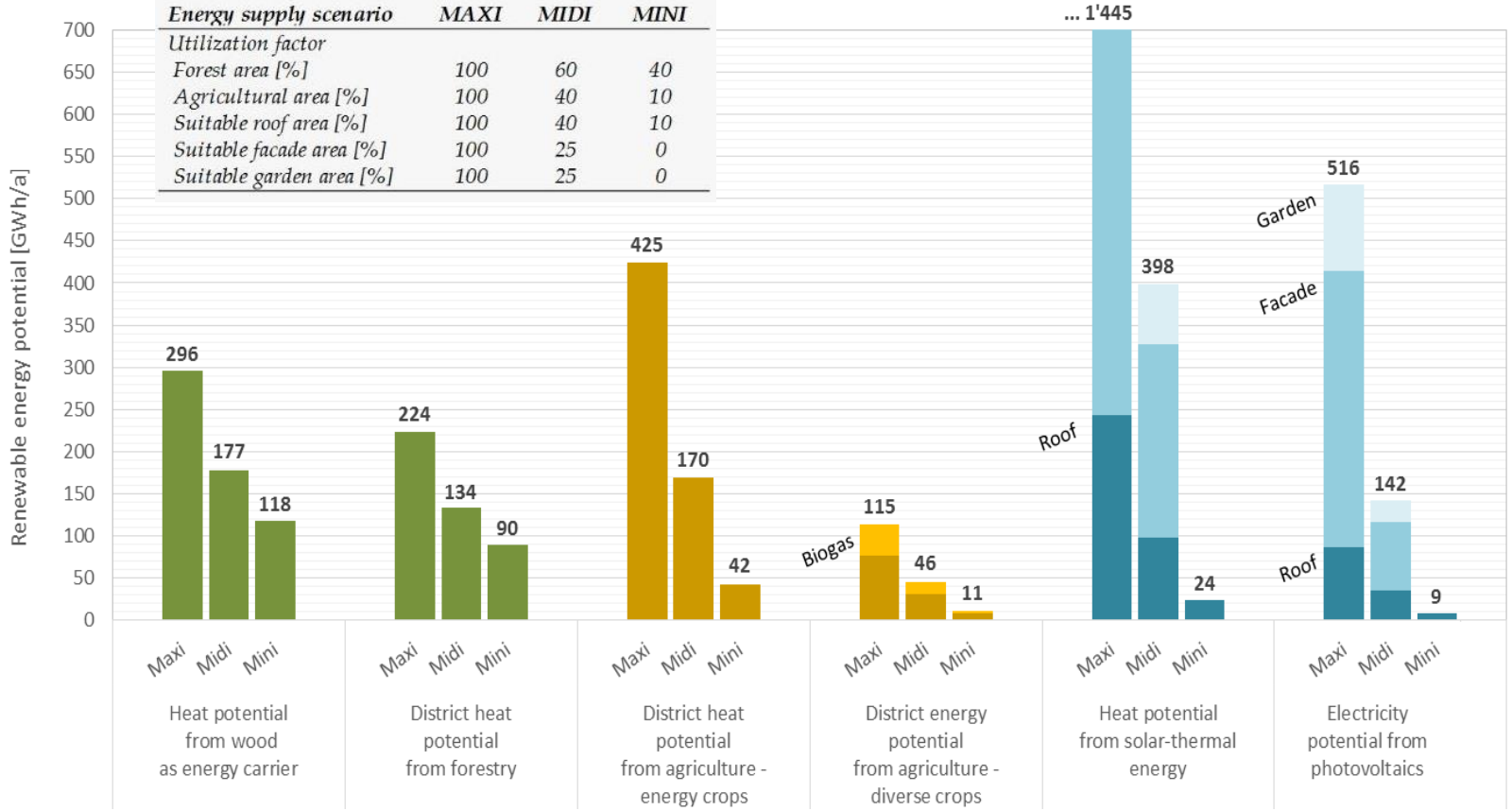
BAU: Energy demand per energy source (GWh/a)



Binder et al., 2016

Renewable energy potential (GWh/a)

Energy supply scenario	MAXI	MIDI	MINI
Utilization factor			
Forest area [%]	100	60	40
Agricultural area [%]	100	40	10
Suitable roof area [%]	100	40	10
Suitable facade area [%]	100	25	0
Suitable garden area [%]	100	25	0



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Aligning regional energy supply and demand (GWh/a)

	DEMAND			SUPPLY POTENTIAL	
Demand scenarios	BAU			MINI	MAXI
Heating systems scenarios	BAU	ALT	BIO		
Wood & Woodchips	161	105	264	118	296
Solar-thermal	11	24	6	24	1445
Heat from DHS	29	30	27	42 (11)	425 (114)
Electricity	206	229	196	9	516

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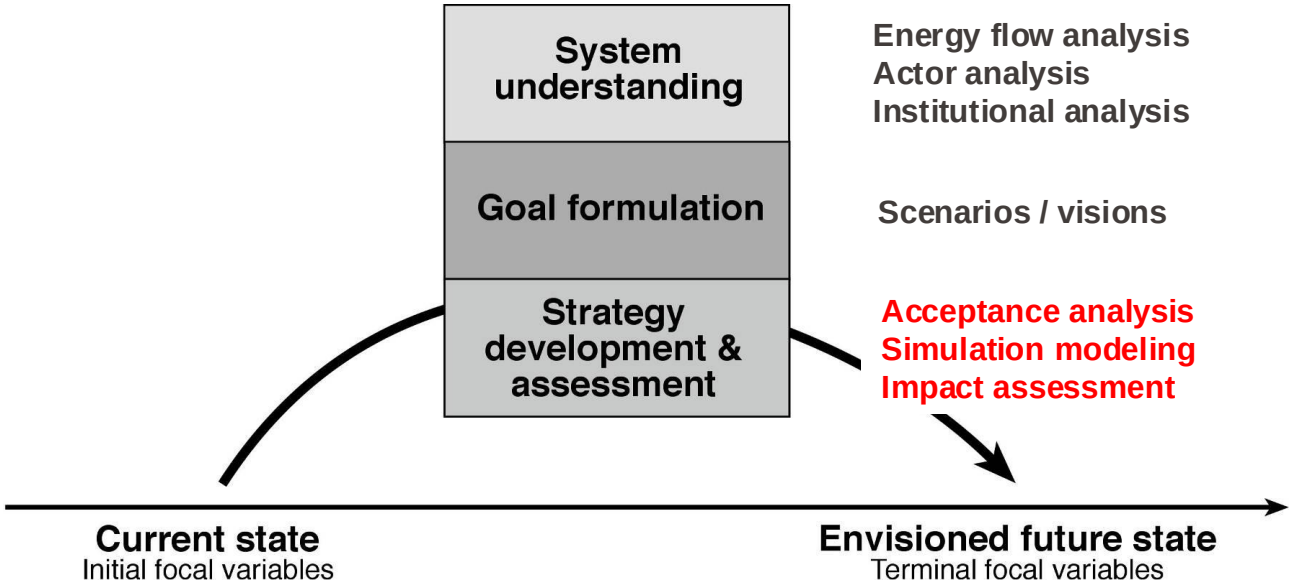
Binder et al., 2016

Elements of transition analysis



Source: Binder et al., 2004

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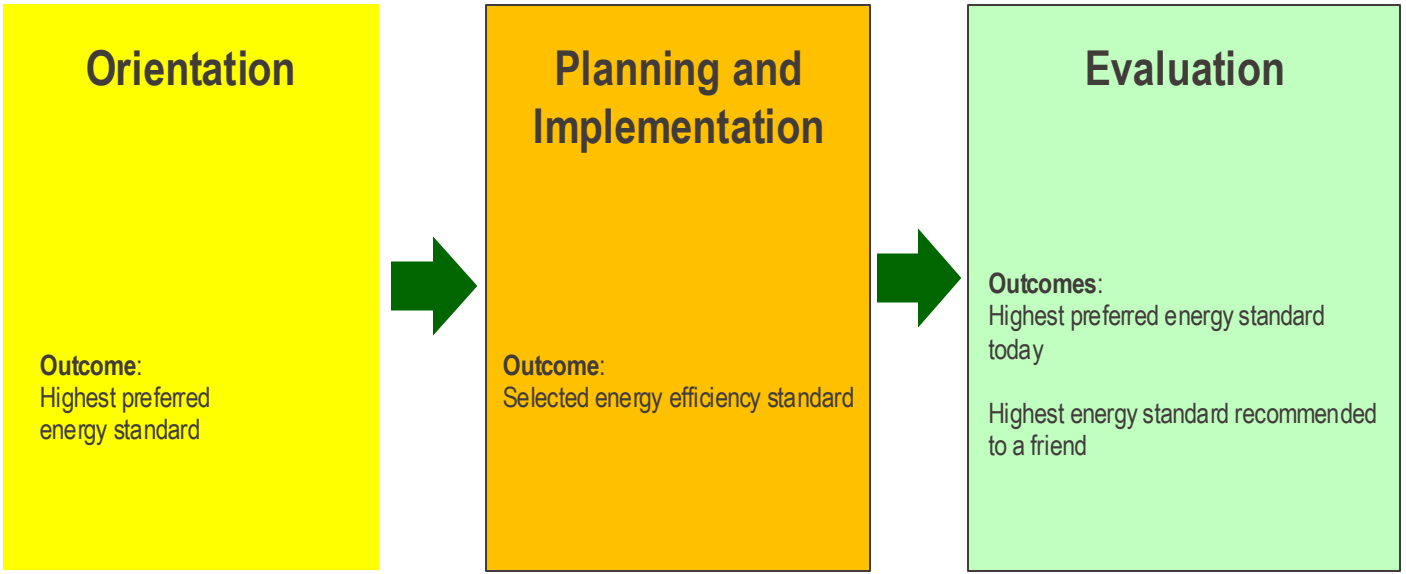
Three phases in selecting and evaluating energy efficiency in renovation and new buildings



Bedenik et al., 2015

Bavaria: Triggers for thinking about energy efficient renovation

	Trigger	Renovators n = 1044	Non-renovators n = 459
Building	Maintenance envelope	65%	40%
	Maintenance interior	58%	48%
	Change heating	15%	6%
Personal factors	Low housing quality	20%	10%
	Personal interest	45%	32%
Context	I saw information campaign	15%	26%

Statistically sign. differences; p<0.01 (rounded values)

Hallwachs et al. in prep.

Triggers regarding energy efficient versus standard renovation

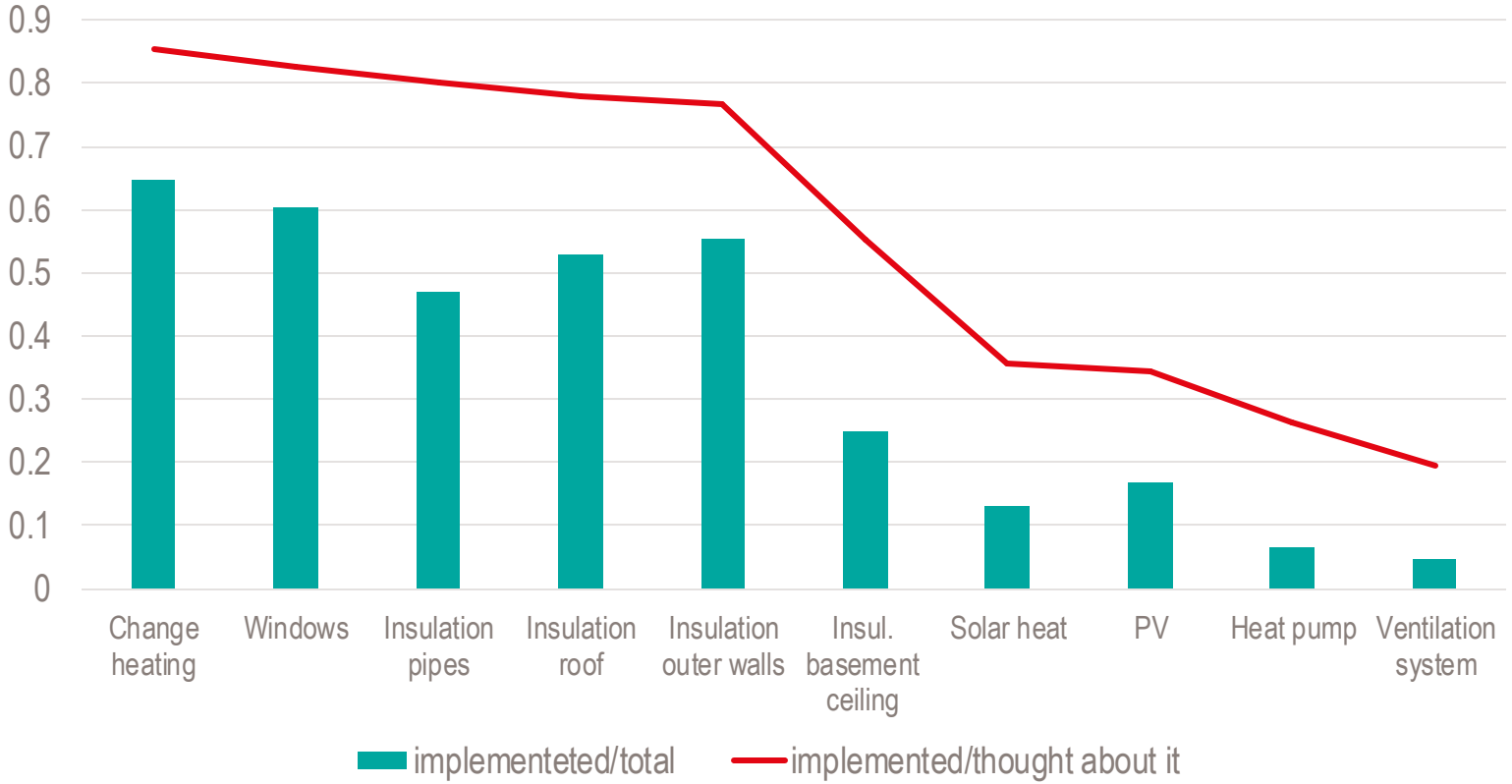
	Trigger	Energy efficient n = 769	Standard n = 275
Building	Maintenance envelope	70%	50%
	Maintenance interior	52%	74%
	Change heating (precaution / legal)	38% / 19%	17% / 3%
Actors	Recommendation expert	35%	23%
	Recommendation network	25%	16%
Personal	Personal interest	50%	31%
	Change in household size ($p<0.05$)	16%	22%
Context	Funding	23%	6%

Statistically sign. differences; p<0.01 (rounded values)

Hallwachs et al. in prep.

Implemented renovation measures

Energy efficient renovators



Hallwachs et al. in prep.

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Some reflections and conclusions

- "The" energy transition is ongoing at different **spatial and temporal scales**
- Co-evolution of **socio-technical systems**
- **Trade-offs:** “faster” transition and “stock” of high energy efficient houses
- Key role of **triggers and experts** for energy efficiency measures
- **Orchestration of tipping dynamics** including social and technical systems

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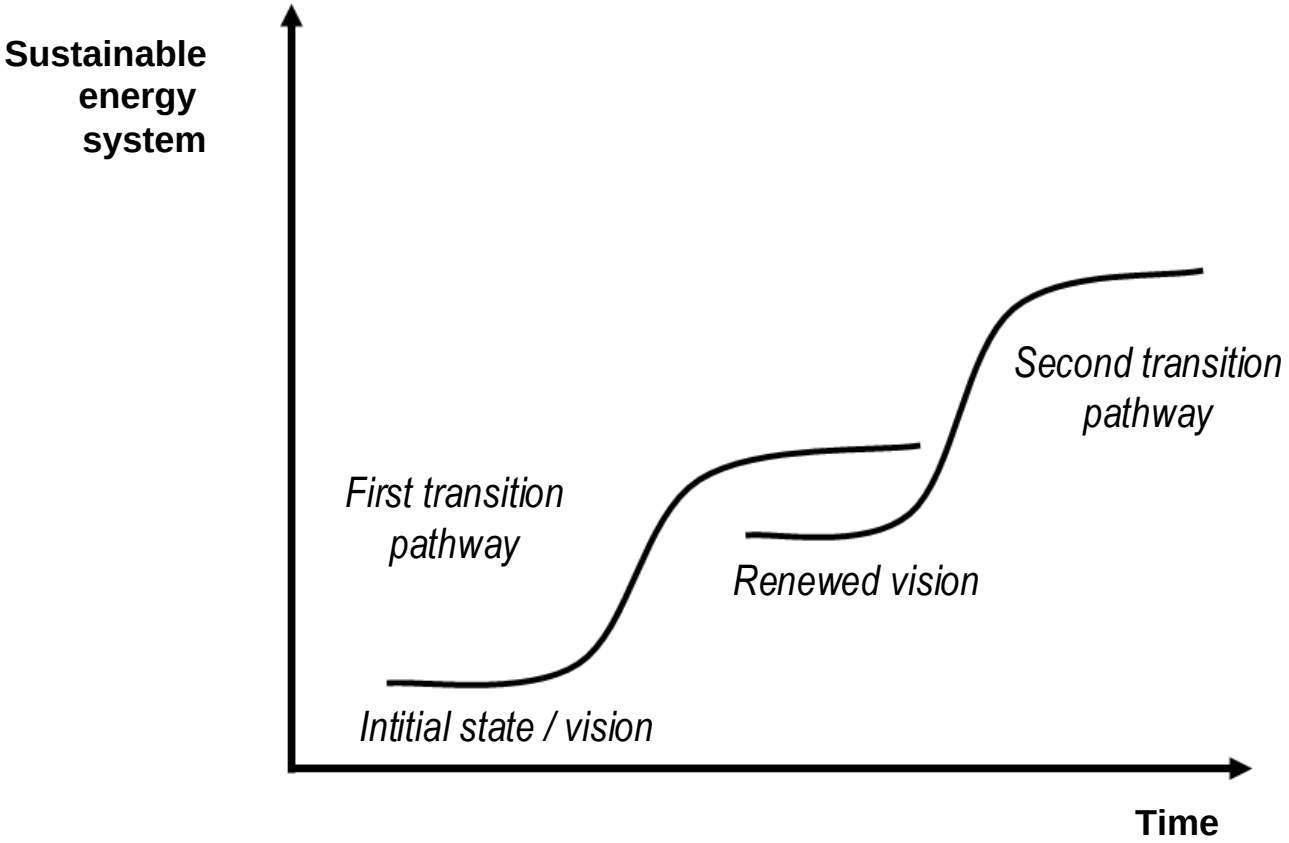
Conclusions: Sequence of transitions



Binder et al., 2019

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Open questions

- How to better understand tipping dynamics?
- How to get beyond infrastructure?
- Which boundary conditions and triggers are needed?
- Co-design of technologies and gadgets?
- What are trade-offs and rebound effects?

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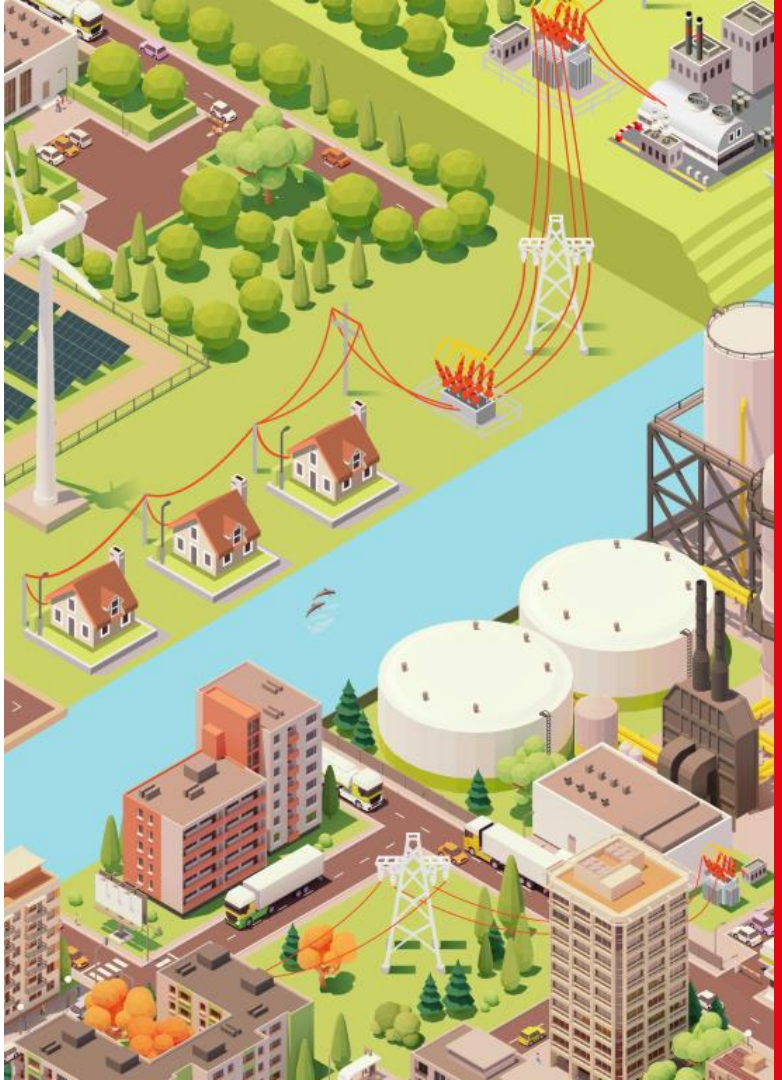

Thank you!

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