ETH zürich

The Impact of Self-consumption Regulation on Individual and Community Solar PV Adoption in Switzerland: an Agent-Based Model

Master Thesis Final Presentation

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A / S Architecture and Building Systems

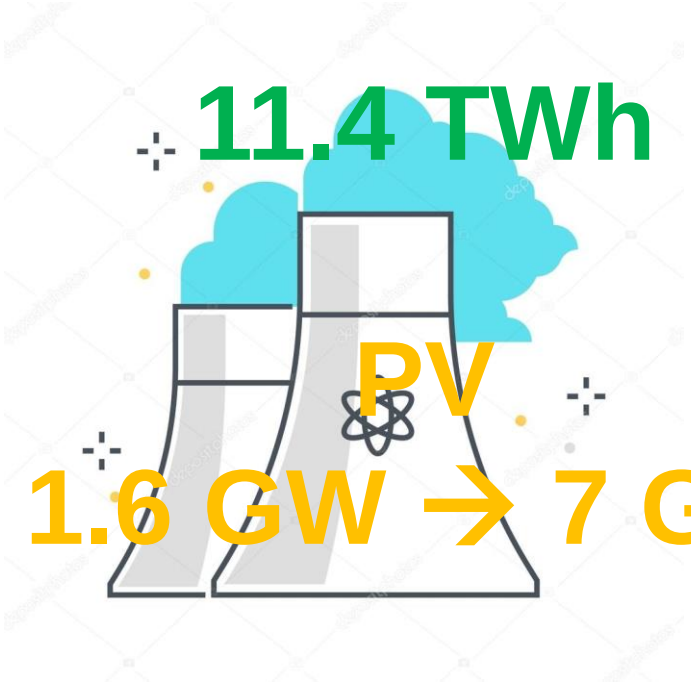
SusTec

Agenda

- **Introduction and Motivation**
- Data and Methodology
- Results
- Conclusion and Discussion

The Energy Transition

2035



11.4 TWh

PV

1.6 GW → 7 GW

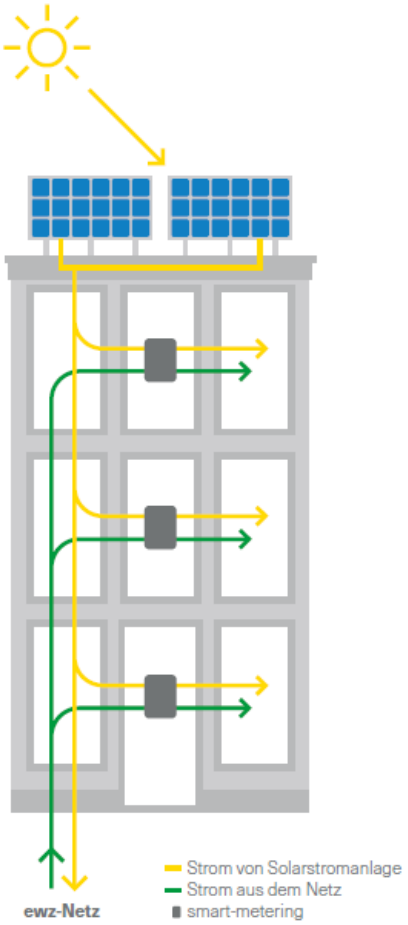
20 TWh

1.4 TWh

Helpful New Regulations – Energy Act 2018

Investment Subsidy until 2030:
up to 30% investment costs
for 2 kW – 50 MW PV Systems

FiT: 7.91 Rp./kWh



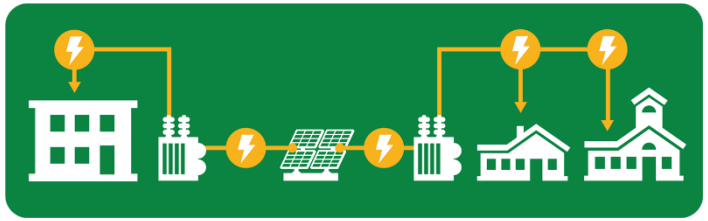
Zusammenschluss für Eigenverbrauch (ZEV) Formation

Self-consumption Communities

Restrictions:

- Can't share across public property, roads, other private properties
- Buildings must be adjacent, common grid connection

ZEV = Community Solar!



Community PV Systems

- Economies of Scale
- Complementary Load Profiles
- Financial Benefits/Products

Problem Statement

- *How will the **dynamics of future solar PV adoption** evolve in urban Switzerland, given the **new regulations** which **incentivize individual solar PV adoption** even more than before, and **allow the formation of self-consumption communities**?*
- *Will community PV adoption outpace individual PV adoption?*
- *What potential policy implications and problems can be foreseen?*

Objectives

- Use of regulations to form potential communities in Zurich
- Develop a decision-making methodology for solar PV adoption – individual and community
- Explore the dynamics of individual and community solar PV adoption under the new regulations for the period 2018-2035 in the district of Alt-Wiedikon, Zurich.
  - Scenarios

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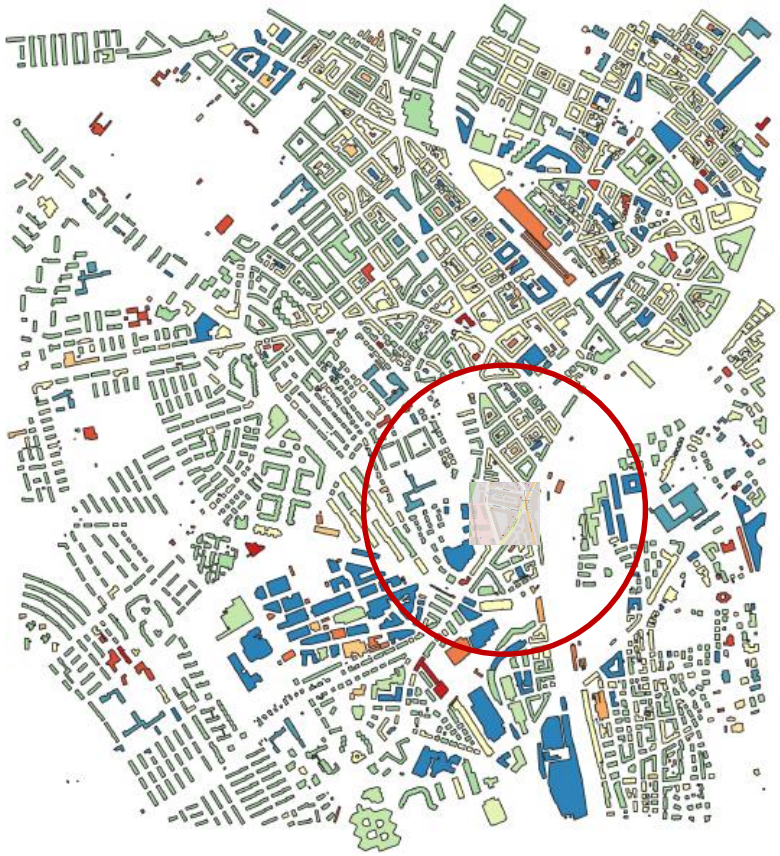
Alt-Wiedikon Buildings Distribution



6856 Buildings
13 Typologies

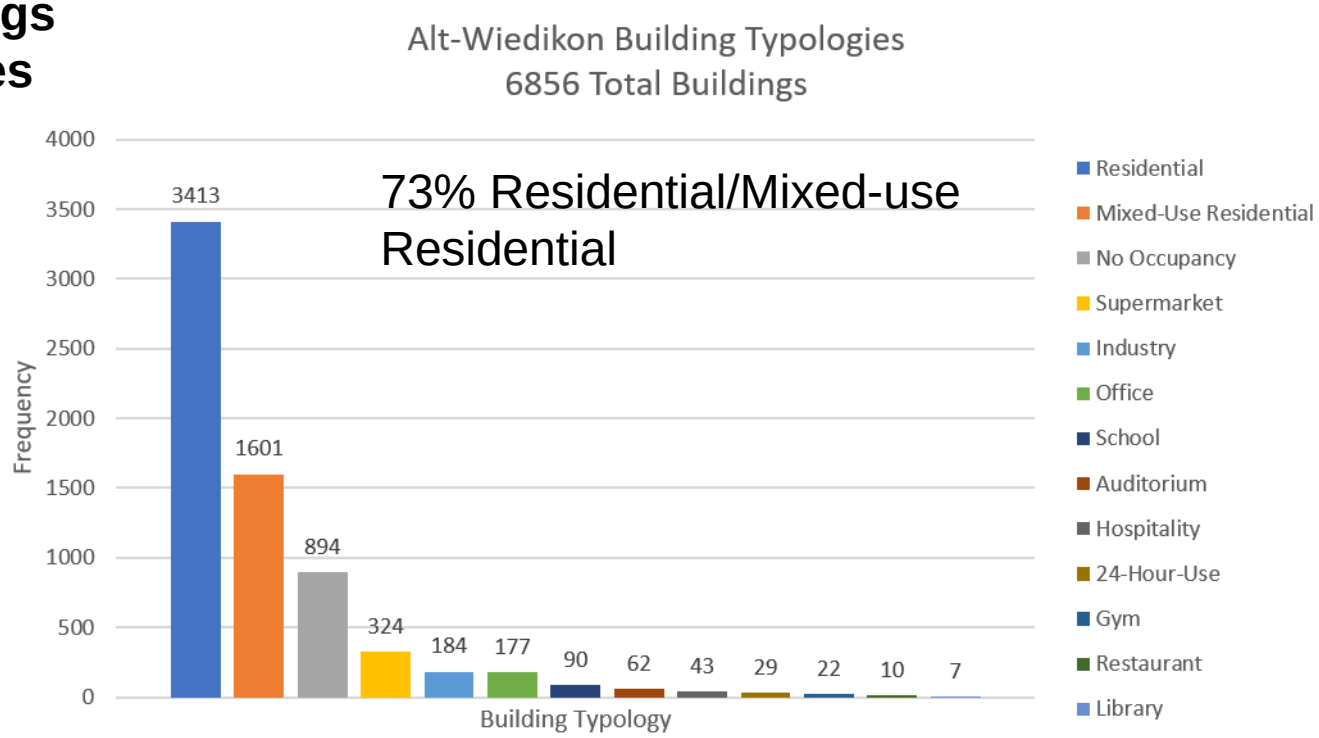
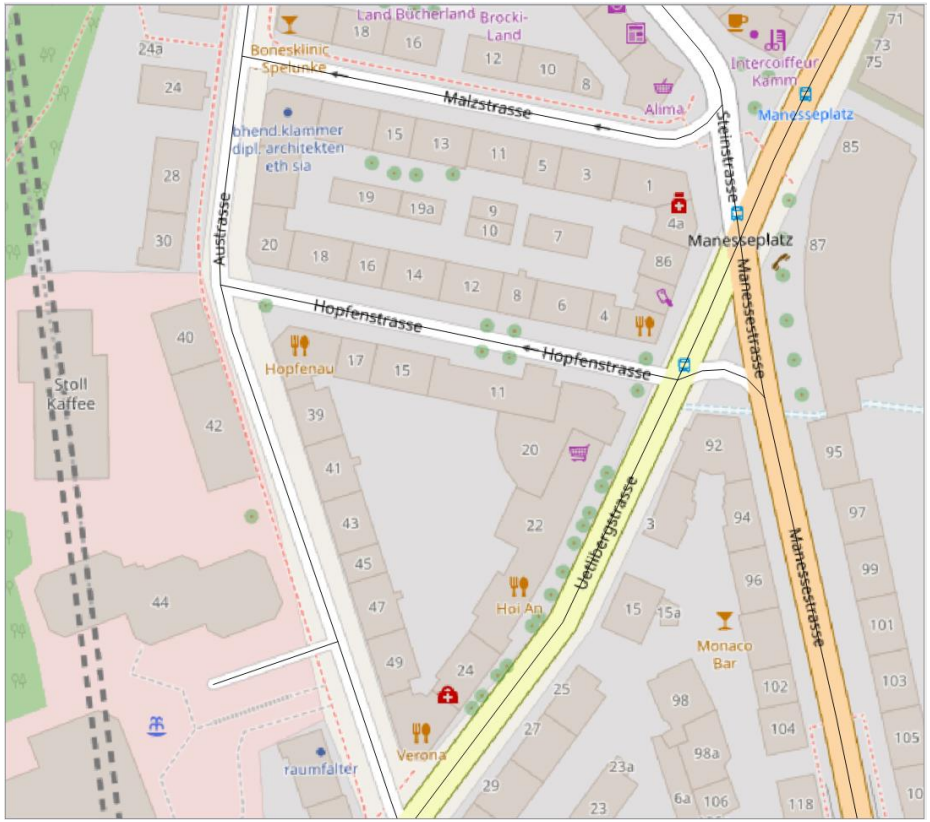


FIGURE 1.1: Building types of the whole district as in the statistics of the City of Zurich

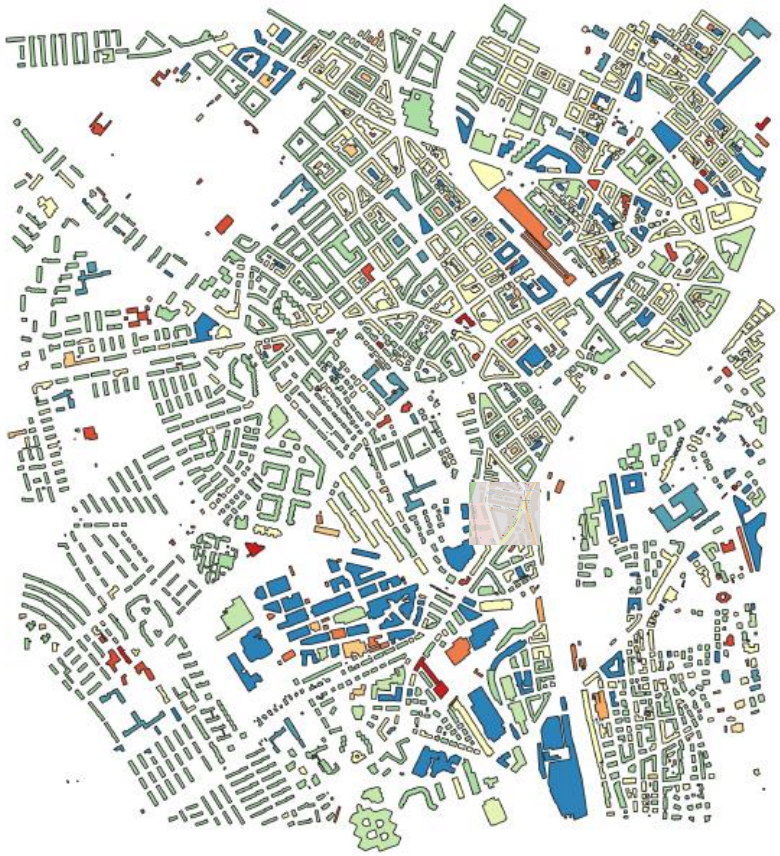
Aggregation of Buildings



14 buildings

1 building block

Alt-Wiedikon Buildings to Building Blocks



6856 Buildings → 1950 Building Blocks

13 Typologies

3 Typologies

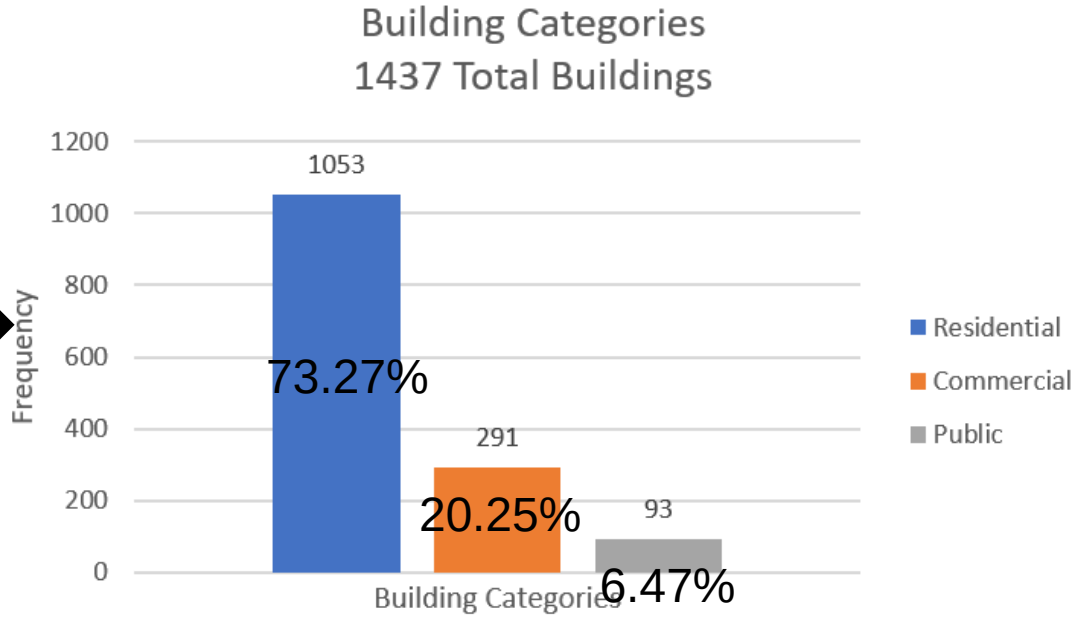
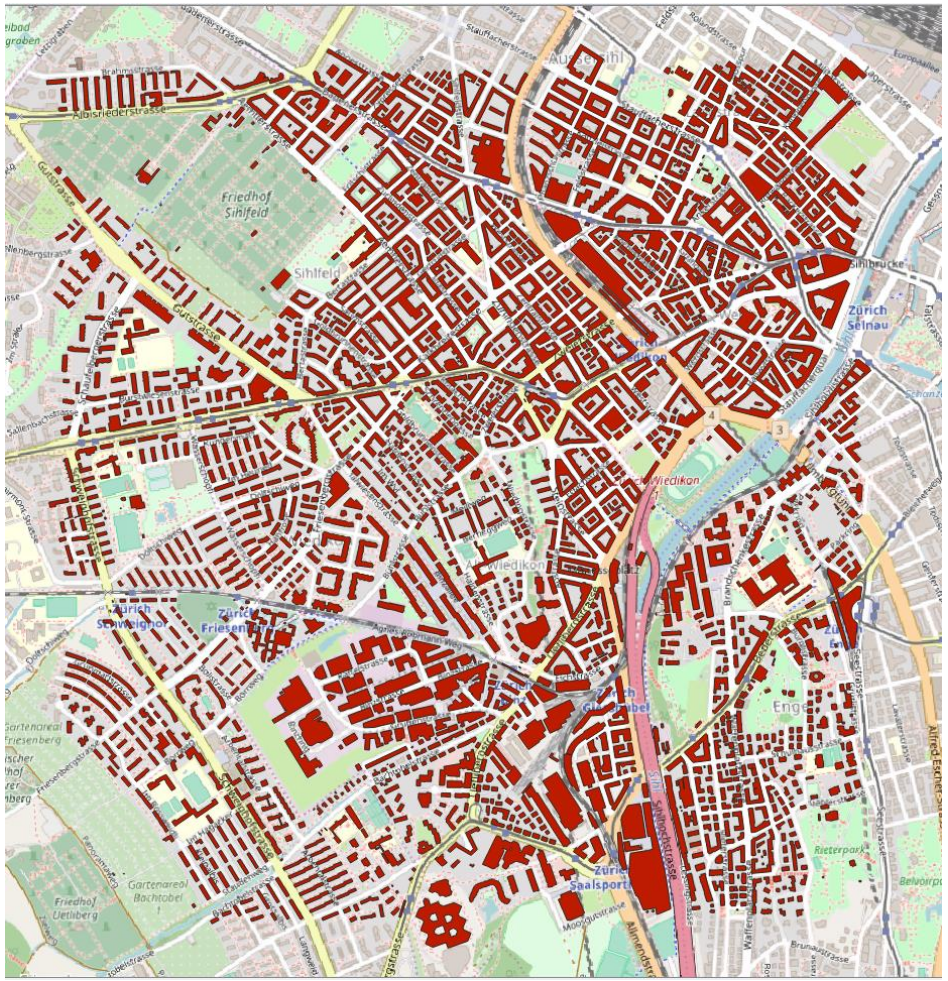


FIGURE 1.1: Building types of the whole district as in the statistics of the City of Zurich

Making Plots in Alt-Wiedikon - OSM

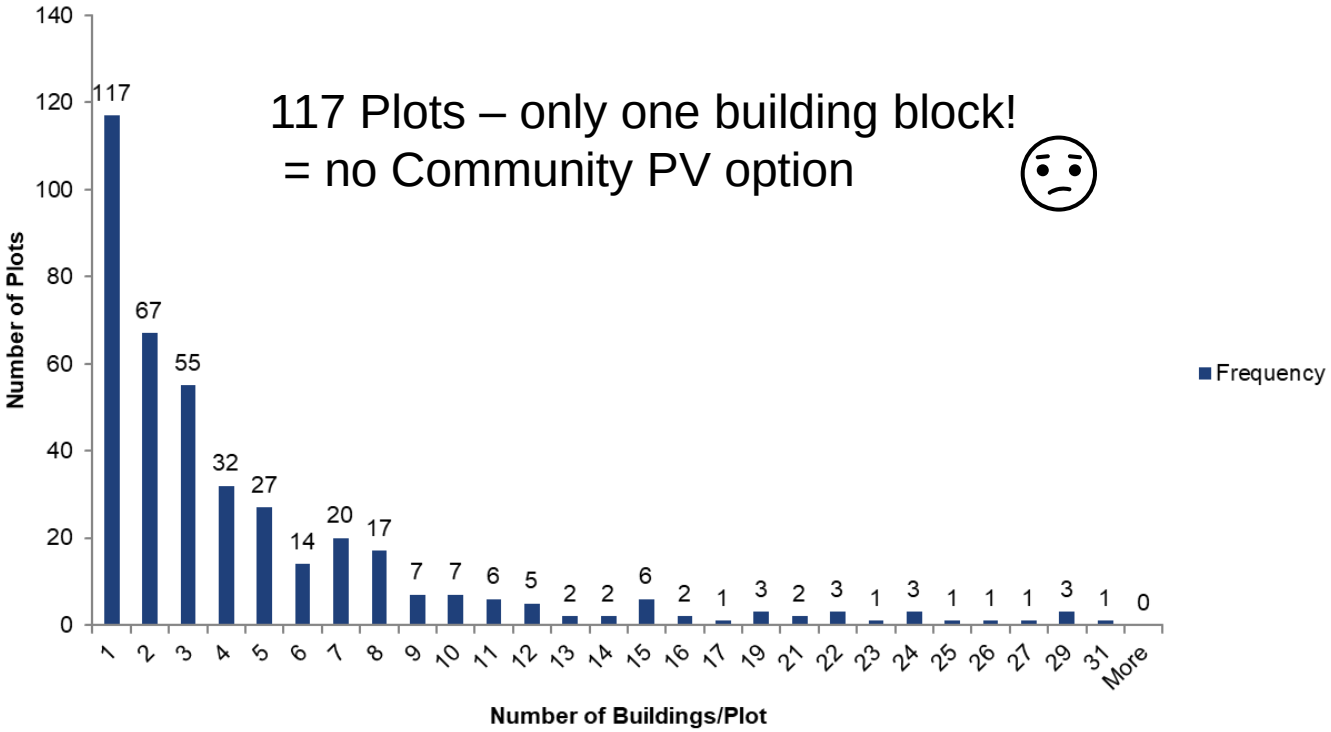


406 Plots

Making Plots in Alt-Wiedikon - OSM

406 Plots

117 Plots – only one building block!
= no Community PV option

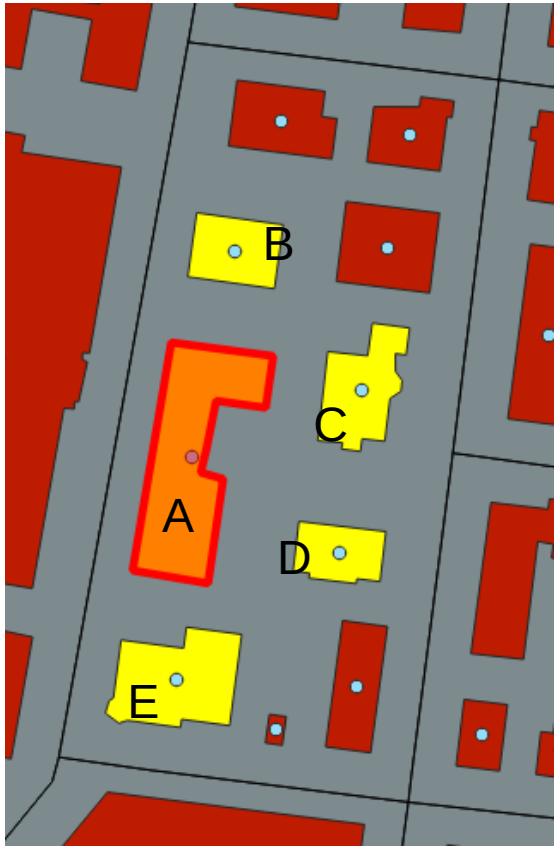


Potential ZEV Members – example of a Plot

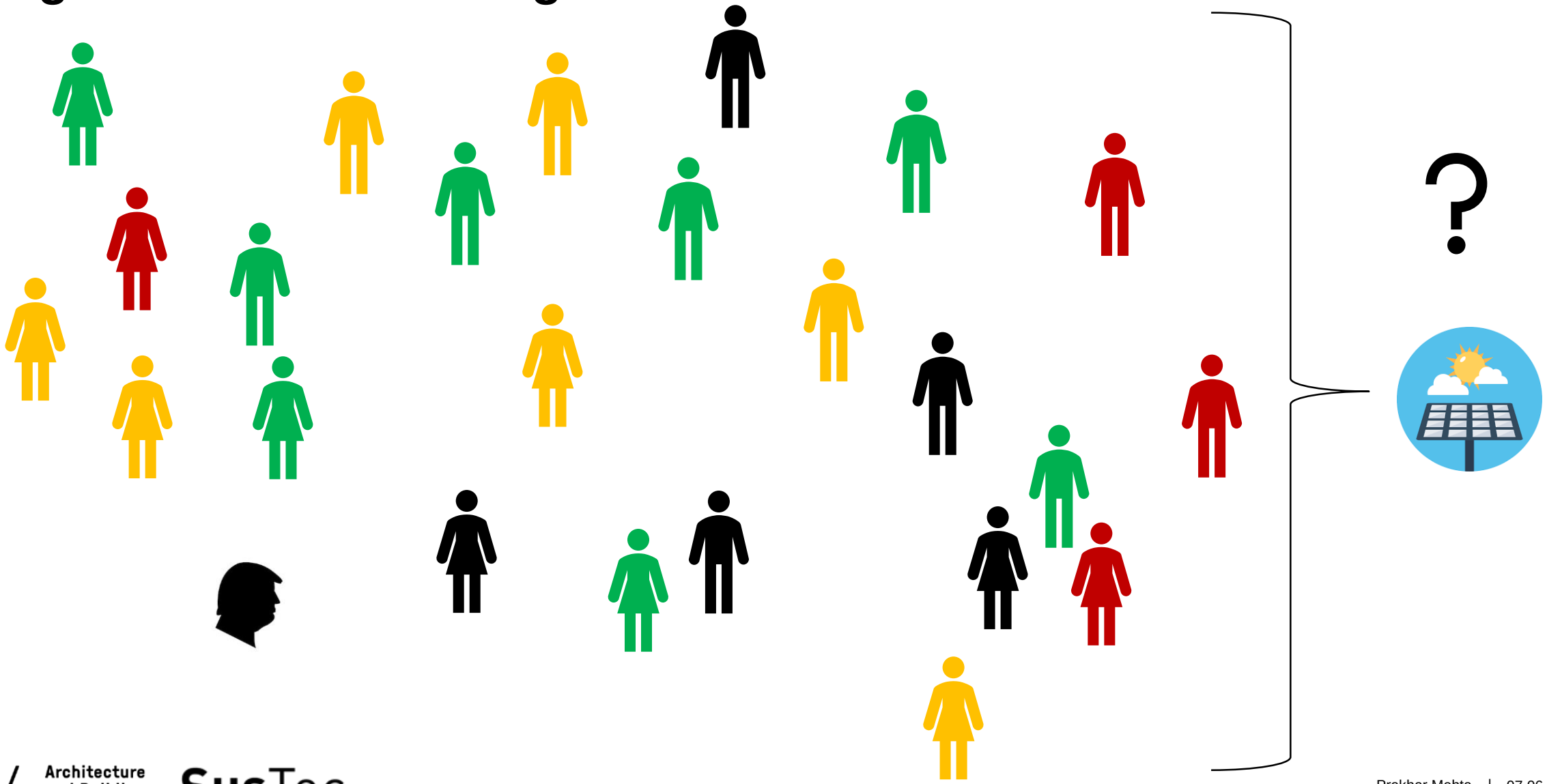
A	B	C	D
B	A	A	A
C	…	D	C
D	…	…	…
E	…	…	…

Number of Possible ZEVs for A: 15

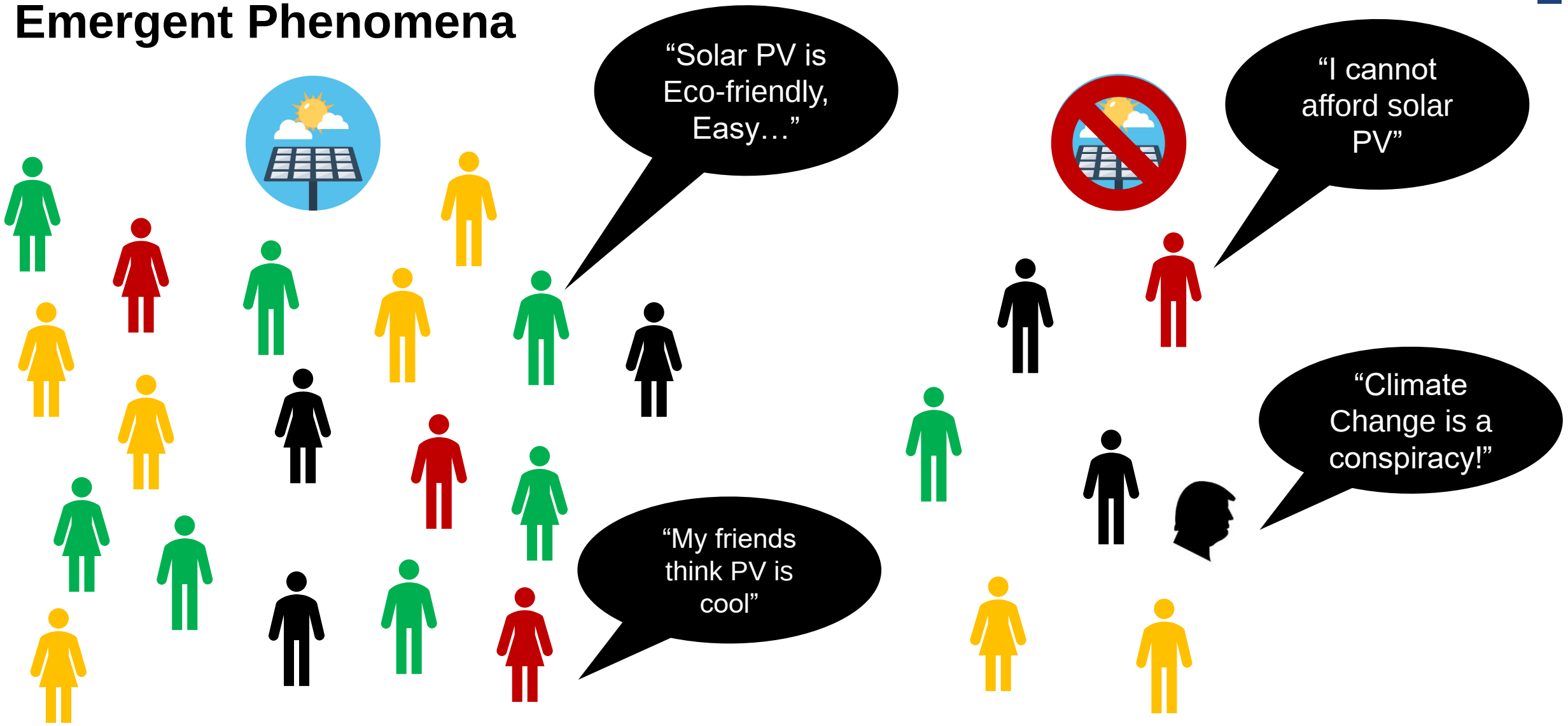
A +B + C + D + E
A +B + C + D
A +B + C + E
A +B + D + E
A +B + C + E
…
A + B …



Agent-based Modelling



Emergent Phenomena

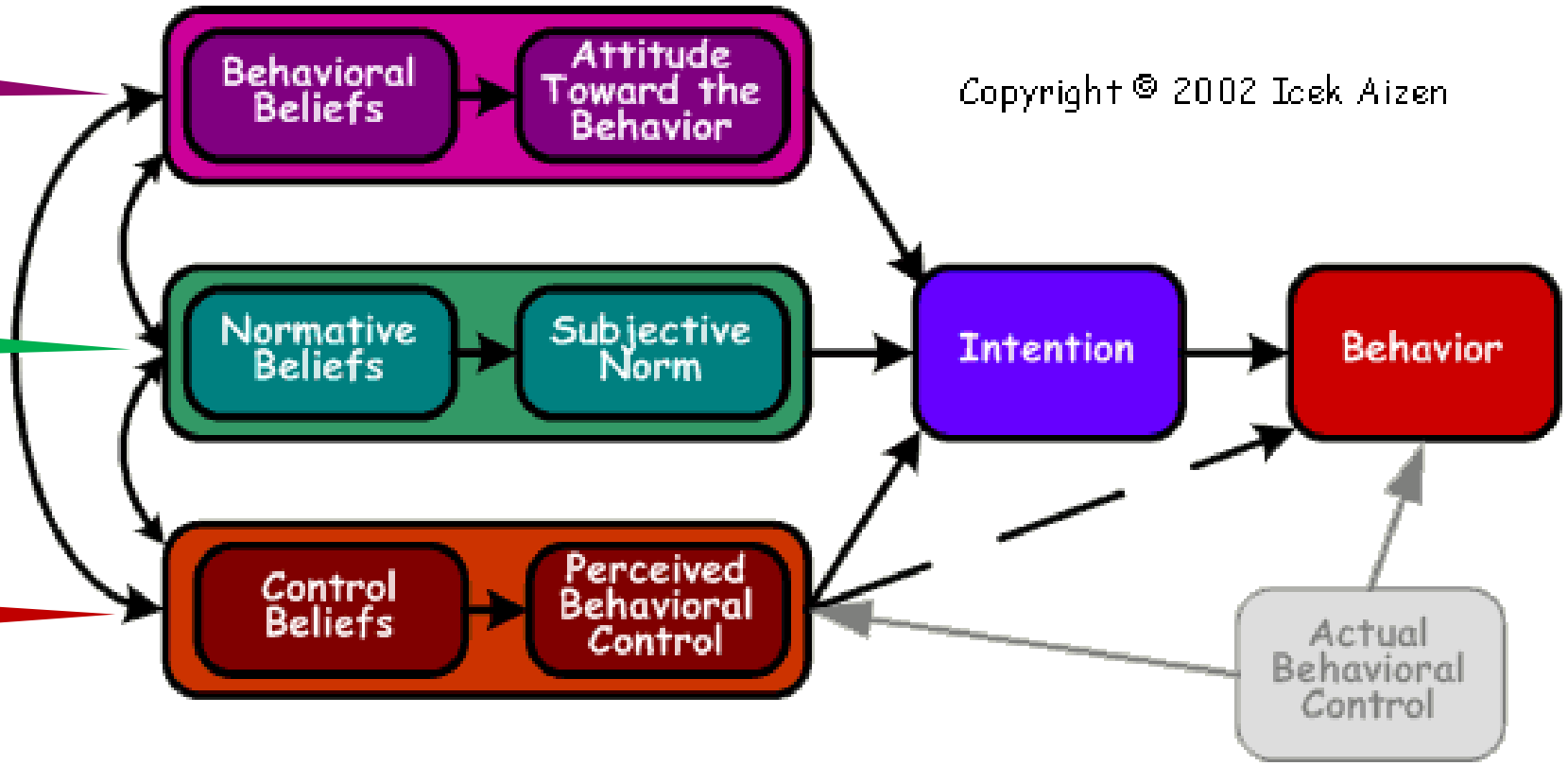


The Theory of Planned Behaviour

"Solar PV is Eco-friendly, Easy…"

"My friends think PV is cool"

"I cannot afford solar PV"



Use of TPB for decision making: Stage I – Idea Generation

Variables

Environmental attitude: [0,1]

+ MINERGIE

Small-world Network : [0,1]

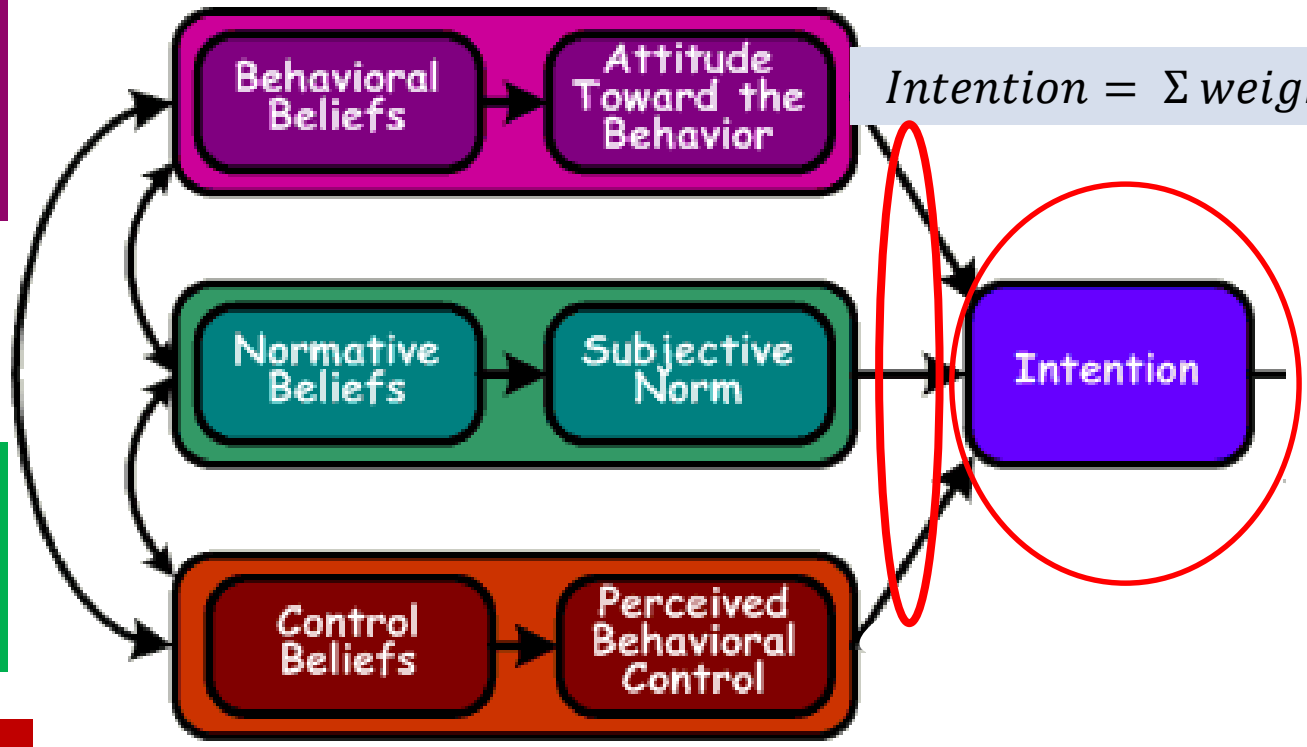
Ratio: $\frac{\#people\ in\ SWN\ with\ Solar}{Total\ \#people\ in\ SWN}$

Neighbour Persuasion:

$\frac{\#people\ in\ Plot\ with{+}ve\ intention}{Total\ \#people\ in\ plot}$

Economic Attractiveness : [0,1]

Profitability Index =1 + $\frac{NPV}{Investment}$



$Intention = \Sigma\, weight * var > threshold$

IDEA Generation
Do I want solar?
Yes/No

Use of TPB for decision making: Stage II – Behaviour

Variables

Environmental attitude : [0,1]

+ MINERGIE

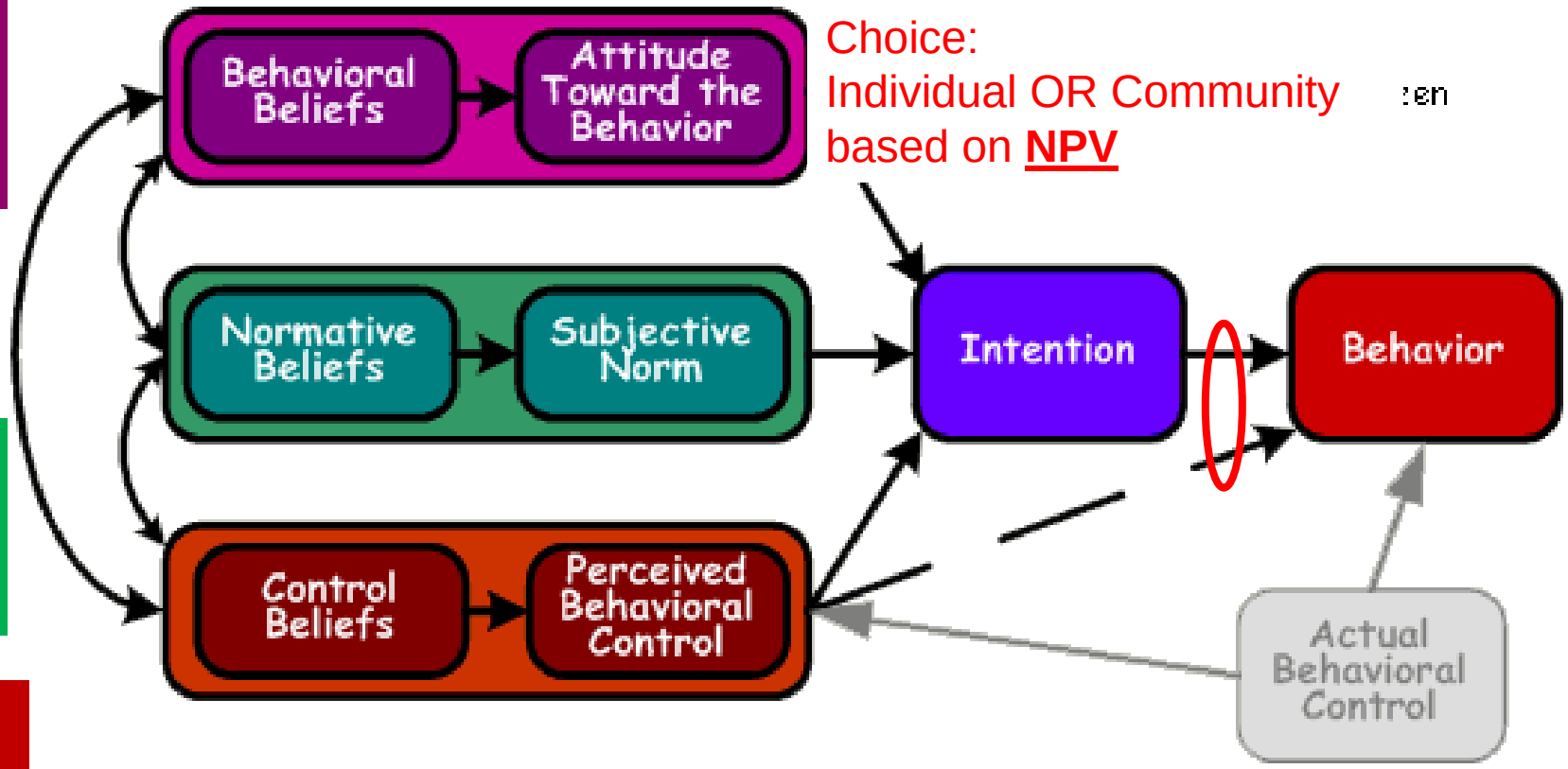
Small-world Network : [0,1]

Ratio: $\frac{\#people\ in\ SWN\ with\ Solar}{Total\ \#people\ in\ SWN}$

Neighbour Persuasion:
$\frac{\#people\ in\ Plot\ with{+}ve\ intention}{Total\ \#people\ in\ plot}$

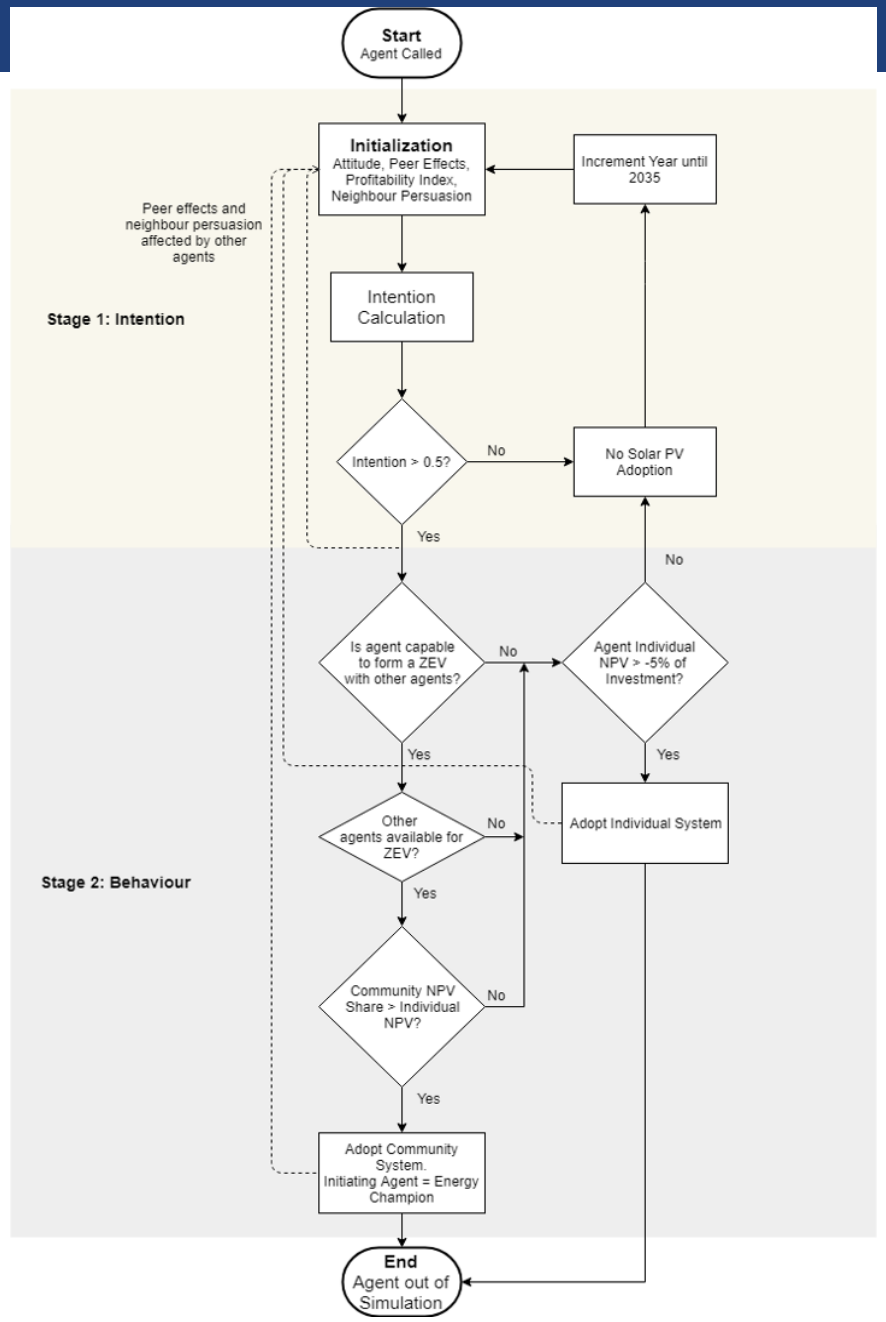
Economic Attractiveness : [0,1]

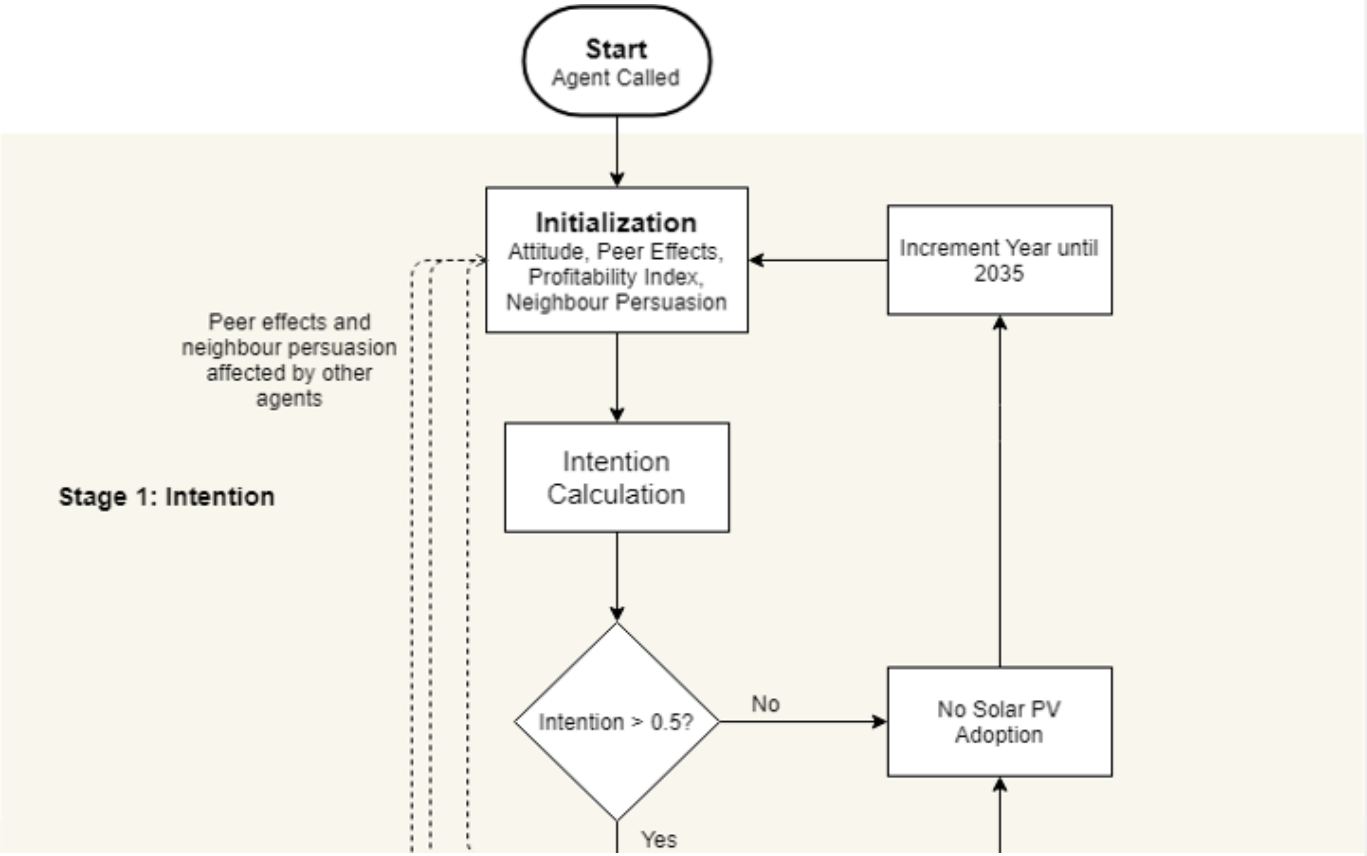
Profitability Index =1 + $\frac{NPV}{Investment}$

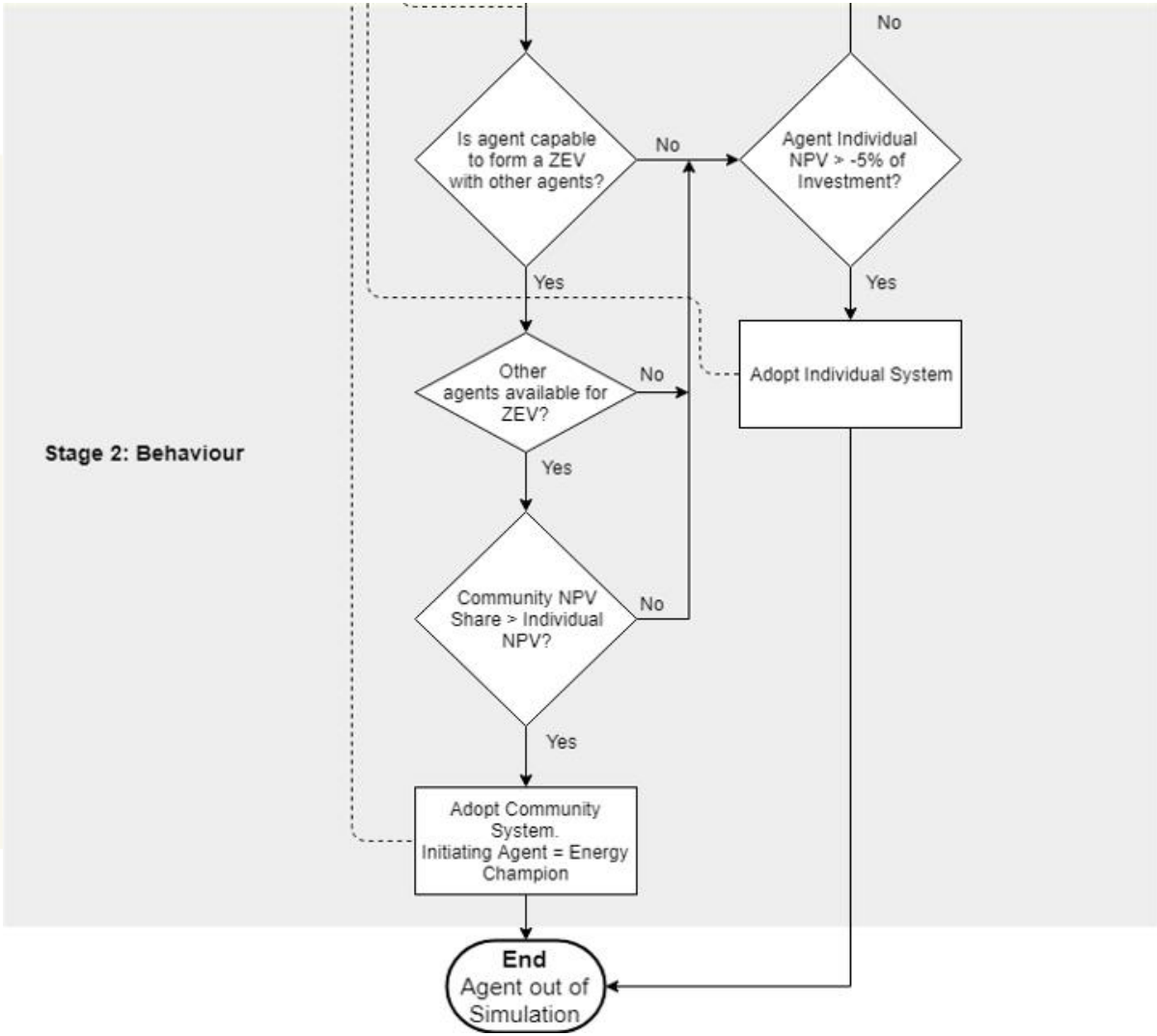


Choice:
Individual OR Community
based on **NPV**

Flowchart Decision-Making




Start
Agent Called
Initialization
Attitude, Peer Effects, Profitability Index, Neighbour Persuasion
Increment Year until 2035
Peer effects and neighbour persuasion affected by other agents
Intention Calculation
Stage 1: Intention
Intention > 0.5?
No
No Solar PV Adoption
Yes


No
Is agent capable to form a ZEV with other agents?
No
Agent Individual NPV > -5% of Investment?
Yes
Yes
Other agents available for ZEV?
No
Adopt Individual System
Stage 2: Behaviour
Yes
Community NPV Share > Individual NPV?
No
Yes
Adopt Community System. Initiating Agent = Energy Champion
End
Agent out of Simulation

Scenarios

- Electricity Prices –
  - **Retail** (< 100 MWh annual demand): 24.3 - 14.4 Rp./kWh
  - **Wholesale** (> 100 MWh): 6 - 5 Rp./kWh
- Unclear if building owners purchase on wholesale markets

Model A – Reduced (~ half the population)

- 716 building blocks < 100 MWh
- **Retail Prices**
- Compensates for CEA Building Aggregation
- 2 Cases:
  - **No-ZEV** → no community solar. Used for calibration
  - **ZEV** → communities allowed < 100 MWh. Compare with no-ZEV.

Model B – Alt-Wiedikon

- 1437 building blocks – entire district
- **ZEV** 2 Cases:
  - **Retail Prices**
  - **Wholesale Prices**

Assumptions

- Buildings → Building Blocks
  - PV Sizes = Max Rooftop Sizes, else 
  - Building Block Sizes quite large = demands large = PV systems large
  - → NPVs amazing! 
  - Building Block – Individual, >1 Building Block = Community → different in reality!
  - Much fewer agents than reality – simpler decision making
  - Cooperation costs – purely monetary indicators used
- Decision making at only owner level: all tenants say YES to a ZEV
- Model calibrated with projected historical trend, not validated
- Over time:
  - Constant – Population, Attitudes, peer network, electricity prices, Subsidies and FiTs, ZEV members
  - Changing – PV Prices, NPVs, Peer Effects  

Methodology Overview

Other Inputs
- Peer effects, environmental attitudes, agent locations and networks
- Prices – PV and Electricity
- Regulations – FiTs, Subsidies and ZEV formation

Building Data, Geometry, etc.

CEA Model
Alt-Wiedikon, Zurich

CEA Output Data Processing

ABM for Building Owners [Individual/Community Adoption]

Results Visualisation

Parameters
- Agent Categories based on building type and ownership
- Time: Yearly time steps until 2035

- Adoption levels Individual v Community PV Systems

Agenda

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- **Results**
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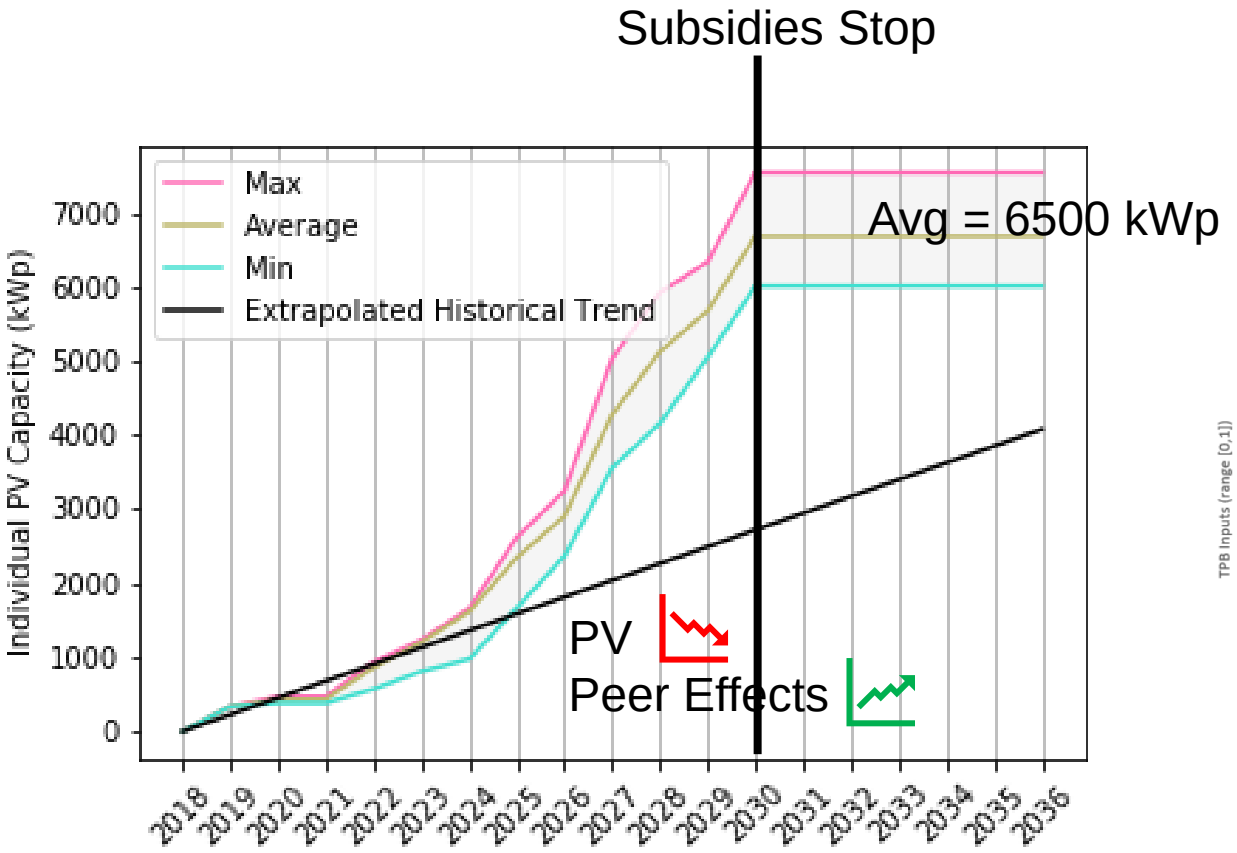
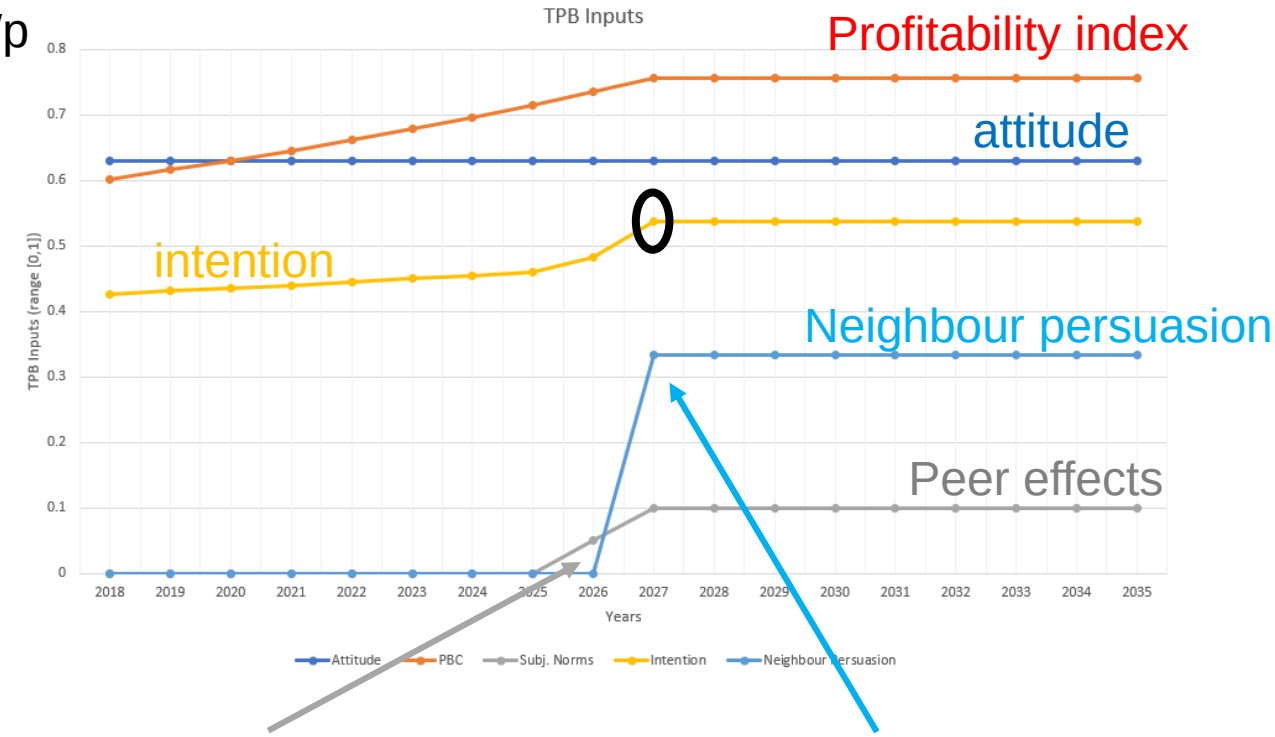
Model A – Reduced

no-ZEV



Targets Exceeded 1.5 times!

An example Agent's Variables and Adoption in 2027

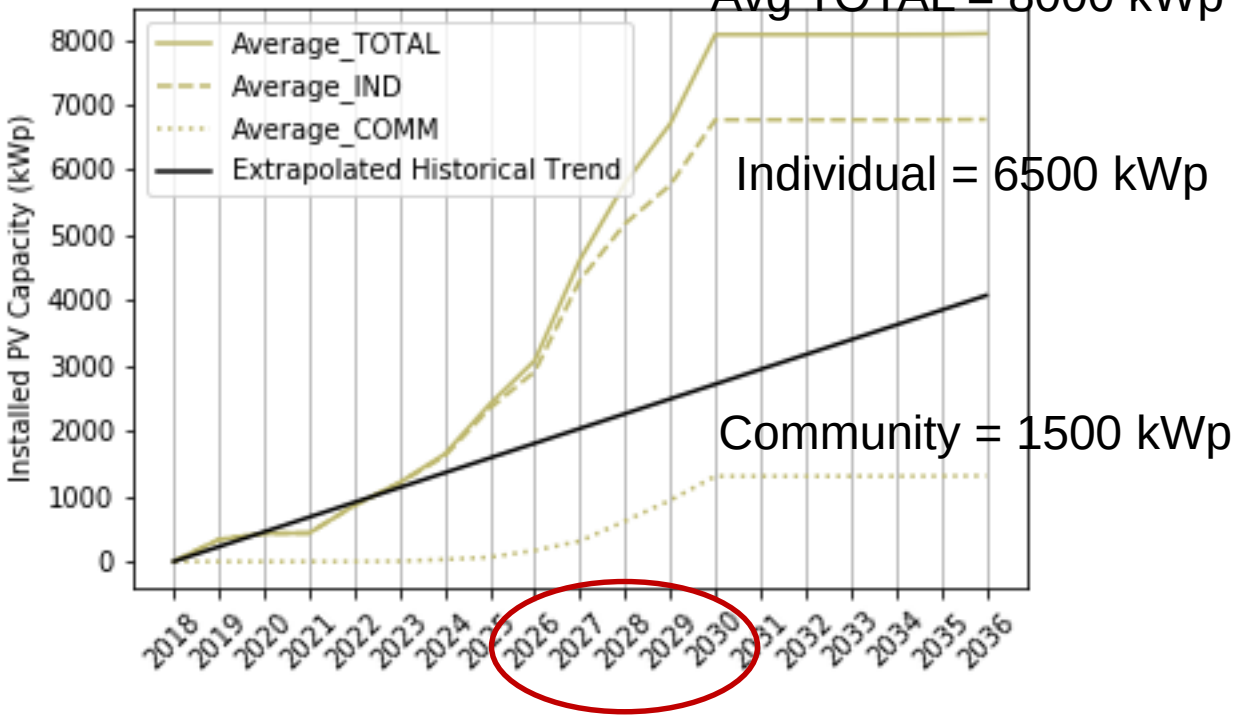


Peers adopted in 2025, 2026

Plot members have positive intention in 2027

Model A – Reduced

ZEV – Community allowed



Avg TOTAL = 8000 kWp

Individual = 6500 kWp

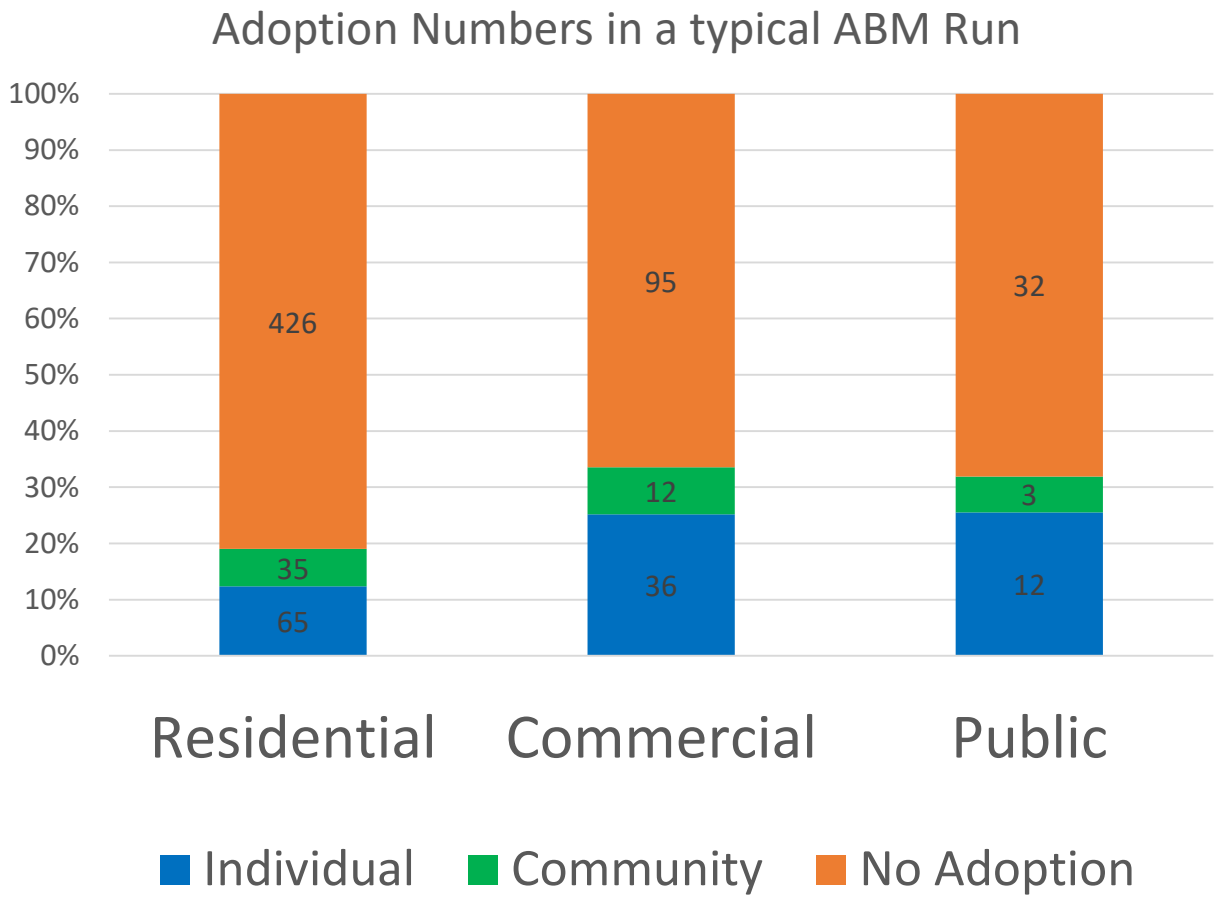
Community = 1500 kWp

- Total Adoption ~ 2x trend
- 2026-2030: ~ 1000 kW/year
- 81% Individual
- 19% Community – only. And delayed.

Model A – Reduced

ZEV – Community allowed

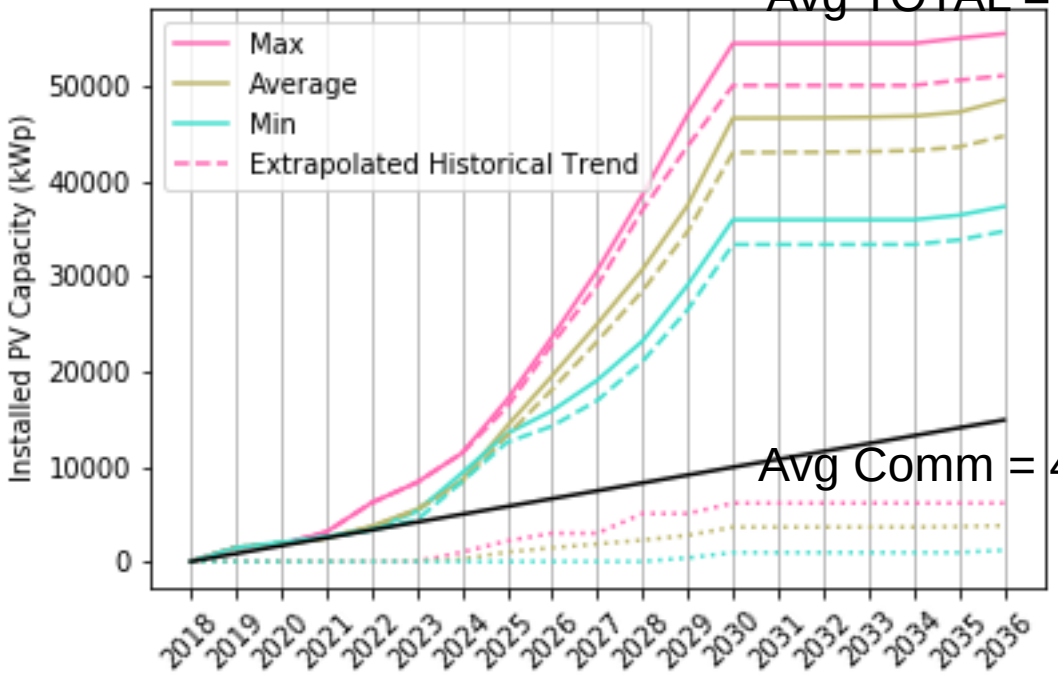
- 22 ZEVs
  - 50 buildings
- 113 Individual Adopters
- Why did they not adopt community?
  - 40%: No other potential ZEV member crossed intention
  - 30%: The community size was exceeding 100 MWh
  - 30%: I'm alone in my plot



Model B – Alt-Wiedikon

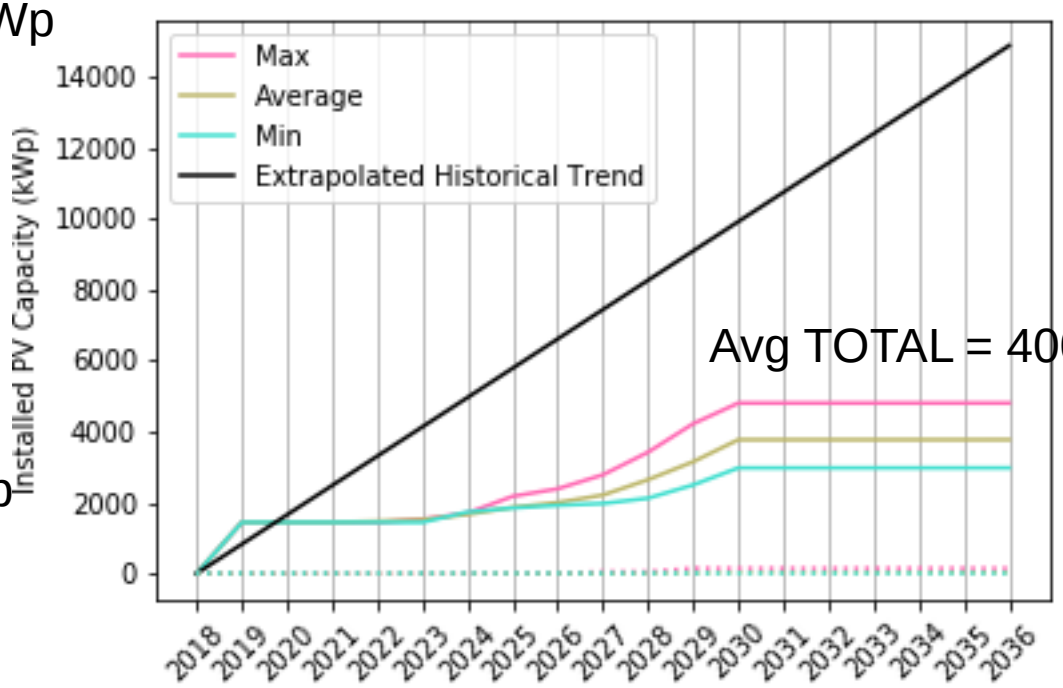
Retail
Expensive Electricity

Avg TOTAL = 48000 kWp



Avg Comm = 4000 kWp

Wholesale: 4 times cheaper electricity!



Avg TOTAL = 4000 kWp

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Conclusion: Key Learnings

- **Targets exceeded.** Subsidies stop and so do the adoptions → PV Prices not falling enough to recover. **Lower subsidy magnitude but extend.**
- Community Formation Difficult and depends on many factors simultaneously
  - Big PVs – economies of scale don't matter
  - Decision-making process – too many things must fall into place for community PV
  - Many buildings – not many options
- Individual adoption i.e. Aggregated buildings **== ZEVs!**
- Electricity price levels extremely important to estimate future adoptions
  - Owners don't know about wholesale markets?
  - Lack of expertise?
- **What will most likely happen – average of Retail + Wholesale adoption levels**

Future Work – Discussion and Limitations

- Consider individual buildings, not blocks
  - → even individual apartments! Better distinction between individual and community
- Varying PV Sizes – consider optimal for all
- Electrical Grid distribution level data – plot formation
  - Vary plot sizes
- Community formation through greater feedback in decision-making
  - Agents convince others in the same year
- Adoption Process: If community not possible, then possibly agents wait
- Social/Individualistic nature of people can be important to consider
- Memory for the agents
- Surveys to gather data

Personal Conclusions

- Deciding how to model decision-making is DIFFICULT!
- ABM can be very subjective
- **Mood Shift: I can see myself doing this for 4 years!**

Thank You! Time for questions and discussion! ☺

@ Danielle
& Alejandro

@ Profs and Teams - A/S and SusTec

@ Peers – positive peer effect ☺

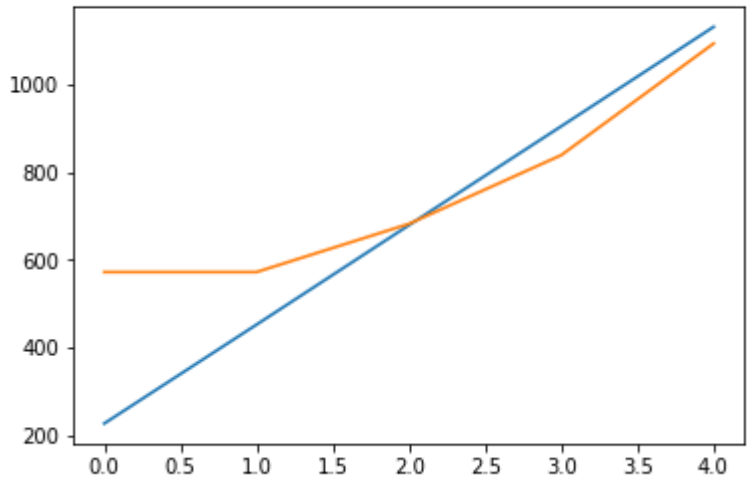
Back-up Slides

Calibration - Model A

Weights	Value
Economic Attractiveness	0.3
Peer effects	0.35
Environmental Awareness	0.35
Negative NPV allowed	YES -15% of Investment costs

Weights	Value
Economic Attractiveness	0.31
Peer effects	0.3
Environmental Awareness	0.39
Negative NPV allowed	YES -5% of Investment costs

RMSE = 167.28717822953436

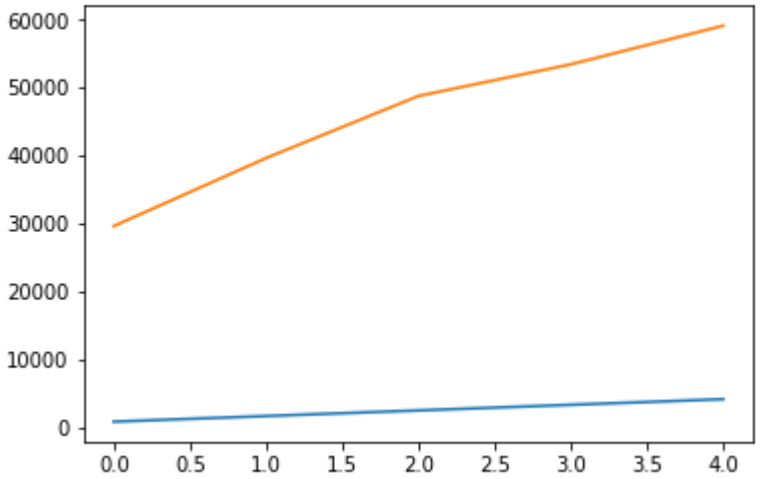


RMSE = 117

Model B – Alt-Wiedikon

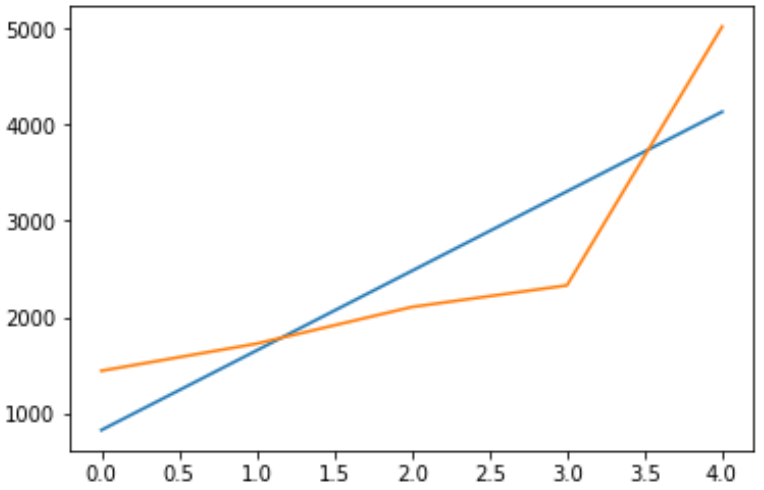
Weights	Value
Economic Attractiveness	0.31
Peer effects	0.3
Environmental Awareness	0.39
Negative NPV allowed	YES -5% of Investment costs

RMSE = 44599.188781860146



Weights	Value
Economic Attractiveness	0.33
Peer effects	0.42
Environmental Awareness	0.25
Negative NPV allowed	NO

RMSE = 673.0002971767547



My case: So. Many. Variables!

Environmental attitudes/beliefs
Technical aspects
Economics
Past opinions
Individualistic/Social

Cost effectiveness
No. of installations in neighbourhood
Feedback based on peer decisions
What Peers Say
- General Social Image of PV
- Small-world Network (Closest people – Friends, Family)

Does agent feel confident enough to do it?
Money/Economic Attractiveness
Time
Skills
Support and Persuasion