Karlsruhe Institute of Technology

Institute for Industrial Production

Determinants of residential photovoltaic and battery storage adoption in Germany

An empirical investigation

Stephanie Stumpf, Daniel Sloot

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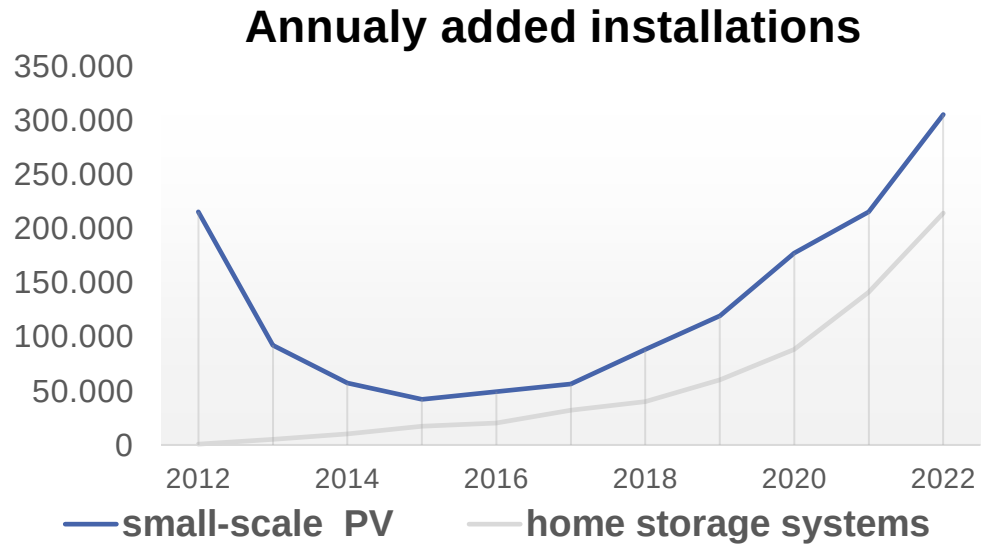
Agenda

- Photovoltaic and battery storage in the residential sector
- Why focus on household photovoltaic and storage adoption?
- Study design
- Research model
- Results and next steps
- Implications

PV and storage adoption in the residential sector

- In 2022, 2.65 million installed PV systems with a nominal capacity of 66.5 GW_p supplied about 12% of Germany's net electricity consumption, including more than 1.5 million small-scale rooftop systems (Bundesverband Solarwirtschaft, 2023)
- In the past years, increasing retail electricity prices, the reduction of feed-in tariffs, and decreasing prices of batteries have made self-consumption increasingly attractive for many households
  - ➢ **About 70 % of small-scale PV systems in Germany are currently installed with a BS**
- The cumulative battery capacity of solar home storage is 5.2 GWh (Bundesverband Solarwirtschaft, 2023)
- PV and BS show different diffusion curves, even though the economic viability of both technologies is closely linked to household electricity price and incentive programs



Source: Bundesverband Solarwirtschaft, 2023

Why focus on household PV and HSS adoption?

- A holistic understanding of the key factors is important to better grasp the diffusion processes of PV and S
- There is extensive research on PV adoption, which tried to explain adoption from different theoretical angles, indicating that both rational and moral motivations are related to adoption decisions
- There is little research on the extent to which BS adoption depends on similar factors

Research questions:

What are predictors of PV and BS adoption?

What are differences between adopting factors of PV and BS?

What are differences between adopters and non adopters?

Study design

Objective

Identification of determinants predicting residential PV and BS adoption in Germany

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Model formulation

- Operationalization of the model with all determinants as reflective, latent variables
  (3-6 items to measure each construct)
- Pre-test (N = 23)

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Sample

- Online survey
  (final sample: N= 809
  initially N = 826)
- Representative of the German population, in terms of
  - Gender
  - Age
  - Income
  - Size of the household

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Final sample

	%
Employment	
Employed	38.5
Self-Employed	5.1
Retired	26.2
Studying	20.6
Not employed	4.9
Other	4.7
Type of building	
Detached House	29.4
Semi-Detached House	7.4
Terraced House	7.5
Multi-appartment Building	52.2
Other	3.5

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Model fitting

Confirmatory factor analysis (CFA)

➢ Final model of 22 latent variables with 85 items
(21 items were deleted after CFA)

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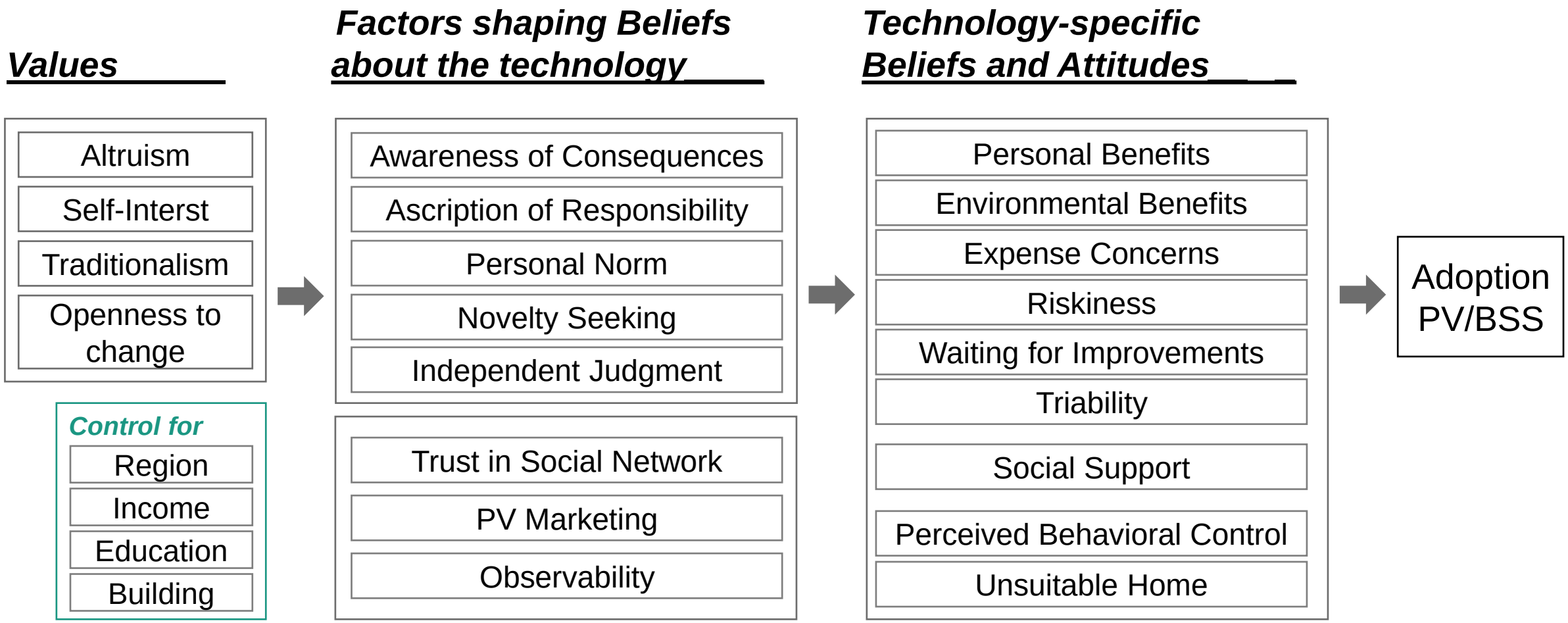
Analysis

Structural equation model (covariance based)

1. PV adoption
2. BS adoption
3. Multigroup analysis (*Building owners vs. non-owners*)

Research model



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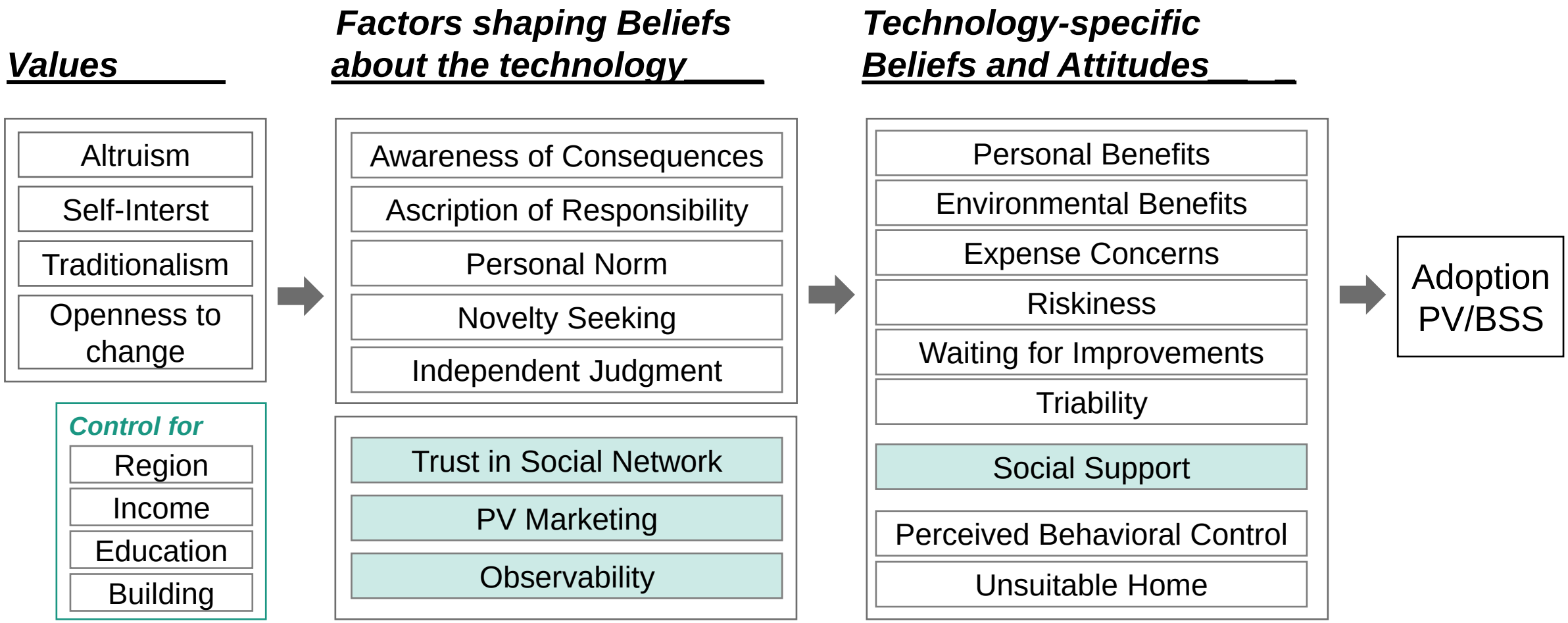

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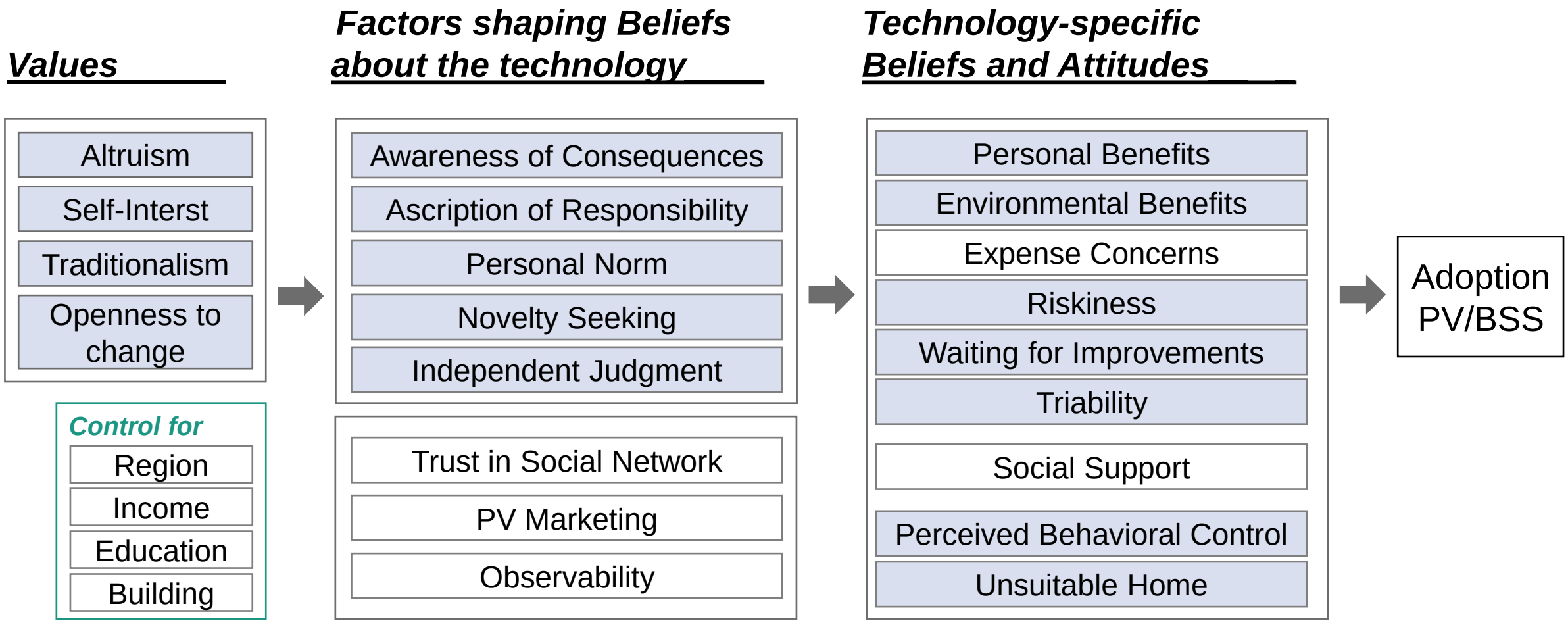

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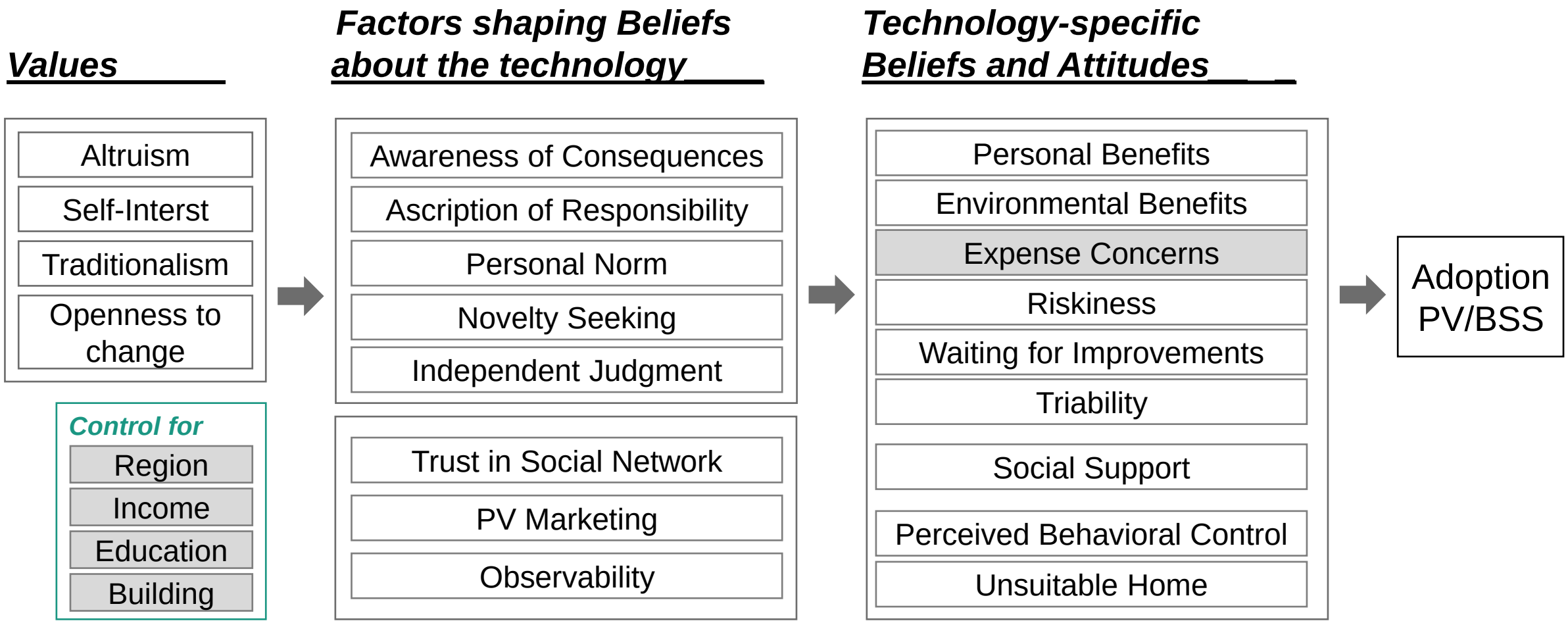

Results – PV

Total effects on intention to adopt PV (standardized coefficients)

Independent Variable	Total
Values	
Altruism	103***
Self Interest	032**
Traditionalsim	-.049***
Openness to Change	.050**
Factors shaping beliefs	
Awareness of Consequences	.067***
Ascription of Responsibility	.087**
Personal Norm	.018
Novelty Seeking	.137***
Independent Judgment	-.024
Trust in Social Network	.043
Exposure to PV Marketing	.083**
Observability	.075***

Independent Variable	Total
Technology-specific beliefs and attitudes	
Personal Benefits	.065
Environmental Benefits	.115**
Expense Concerns	-.267***
Riskiness	.107
Waiting for Improvements	-.0063
Social Support	.230**
Perceived Behavioral Control	.202***
Unsuitable Home	.030
Household Constraints	
Income	-.004
Education	-.007
Type of Building	.183***
Age	.015
Region	.036
R^2	**.388**

*** $p \leq .001$; ** $p \leq .01$ **CFI:** .910 **TLI:** .896 **RMSEA**: .041

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Results – BS

Total effects on intention to adopt BS (standardized coefficients)

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Altruism	.094***
Self Interest	.034
Traditionalsim	-.049***
Openness to Change	.057**
Factors shaping beliefs	
Awareness of Consequences	.050***
Ascription of Responsibility	.104
Personal Norm	.004
Novelty Seeking	.153***
Independent Judgment	-.026***
Trust in Social Network	.036***
Exposure to PV Marketing	.103**
Observability	.078***
Technology-specific beliefs and attitudes	
Personal Benefits	.155***
Environmental Benefits	.101
Expense Concerns	-.325***
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Income	-.001
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Results – Controls and Multigroup analysis

- Household constraints
  - Income, education, age, and region have no significant effect on adoption
  - Type of building has effect on adoption (also on NoveltySeeking, PBC, unsuitable home, and Subjective Norm)
- Significant difference between owners and non-owners
- Expense concerns affect technology adoption intention significantly different for owners and non-owners

Implications

- Social Support and Perceived Behavioral Control (PBC) seem to be positive predictors for both PV and BS, while Expense Concerns has a negative effect for both technologies
- As expense concerns negatively impact both technologies, incentive programs might still be a major driver for diffusion
  - The negative effects of expense concerns on BS seem to be higher than on PV
  - For BS, belief in the relative advantage of the technology has a significant impact; not for PV
- PBC is important
  - ➢ Access to the technologies is central
  - ➢ Regulation for rented buildings may be important
- Also social variables have been shown to be an important driver for both technologies
  - ➢ Communication initiatives might be used to impact diffusion

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Institut für Industriebetriebslehre
und Industrielle Produktion

Thank you four your attention!

stephanie.stumpf@kit.edu

Backup

Literature

- Bundesverband Solarwirtschaft e. V. (2023): „Statistische Zahlen der deutschen Solarstrombranche (Photovoltaik)“, Berlin.
- Bundesverband Solarwirtschaft e. V. (2023): „Statistische Zahlen der deutschen Solarstrombranche (Speicher/Mobilität)“, Berlin.
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- Girod, B., Mayer, S., & Nägele, F. (2017). Economic versus belief-based models: Shedding light on the adoption of novel green technologies. *Energy Policy, 101*, 415-426.
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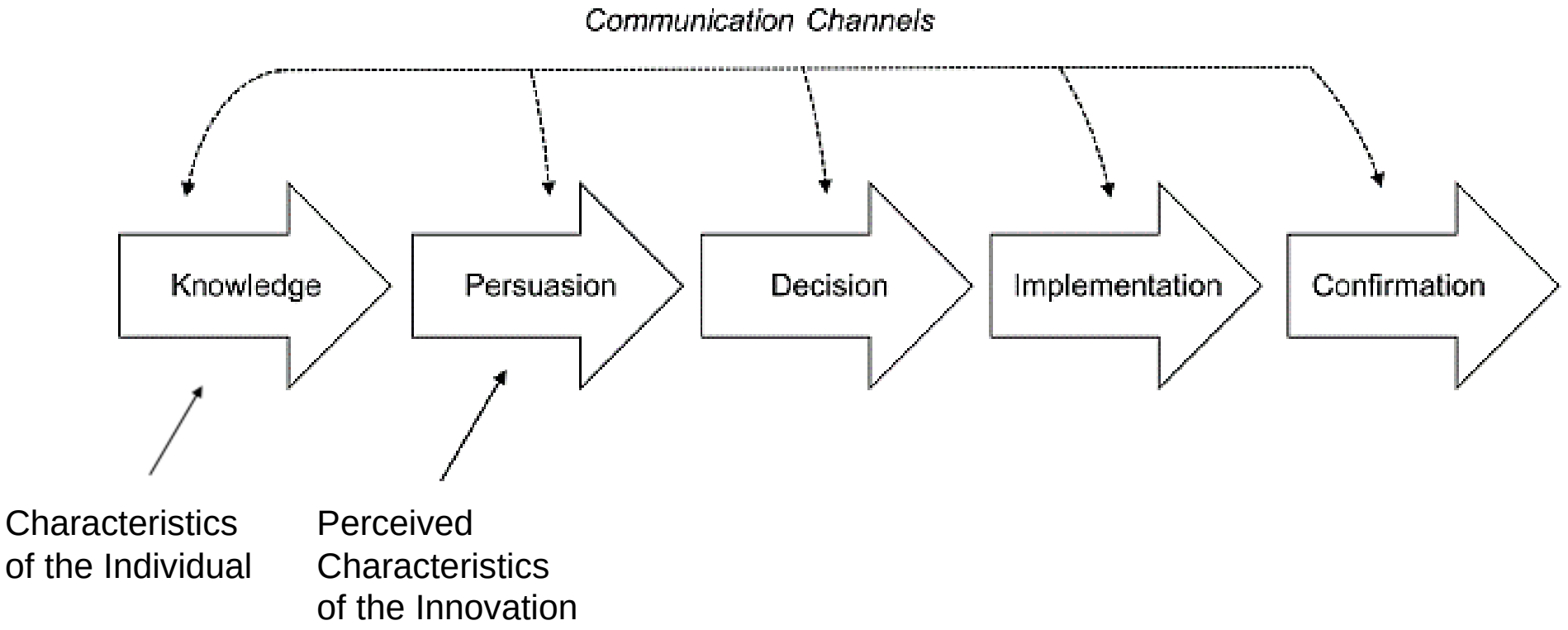
- Zhang, H., & Vorobeychik, Y. (2019). Empirically grounded agent-based models of innovation diffusion: a critical review. *Artificial Intelligence Review, 52(1*), 707-741.

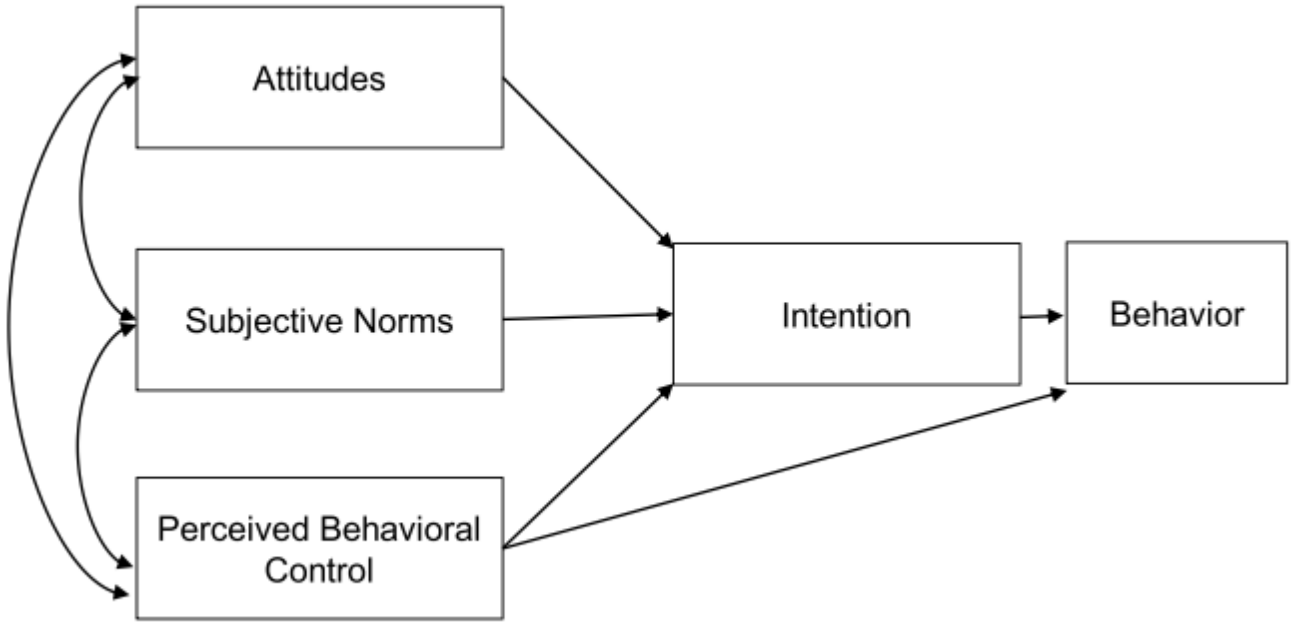
Empirical investigation of residential PV & PVS adoption
Theoretical models

Diffusion of Innovation (Roger 2003)



Empirical investigation of residential PV & PVS adoption
Theoretical models

Theory of Planned Behavior (Ajzen & Fishbein, 1980)



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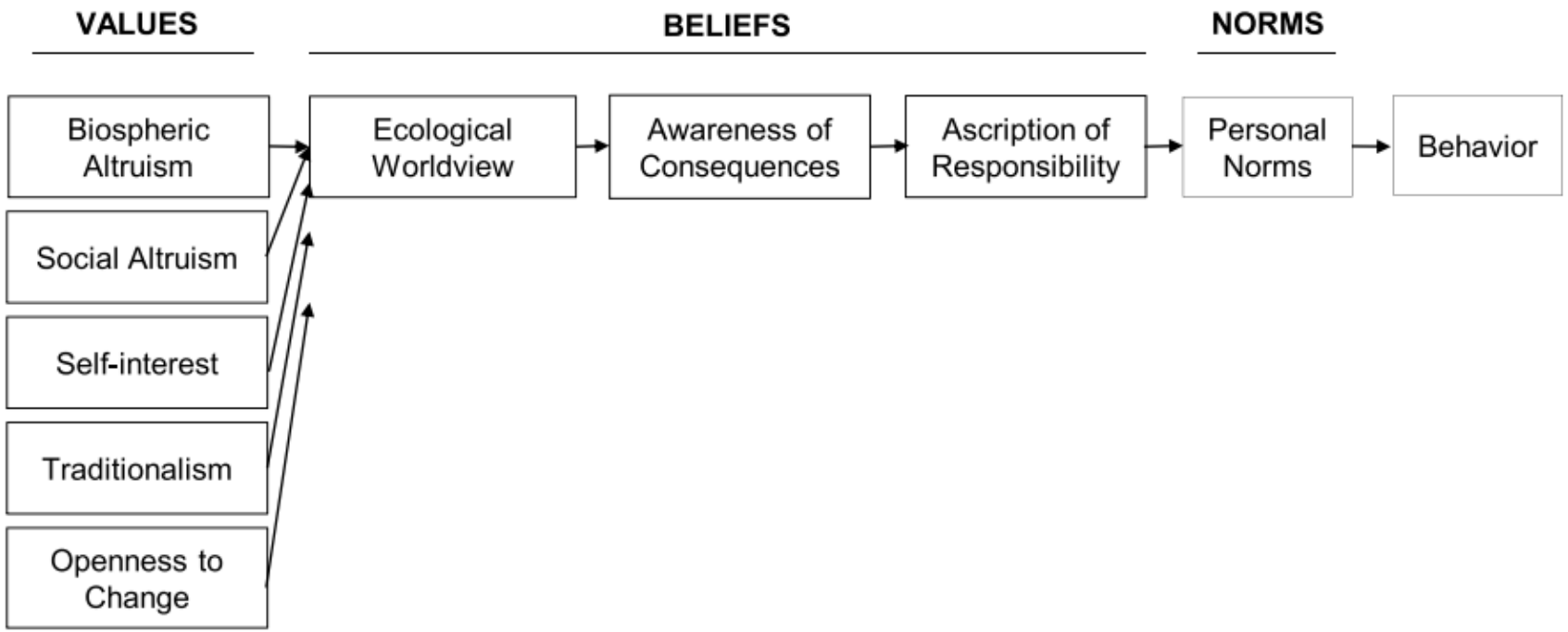
Value-Belief-Norm Theory (Ajzen & Fishbein, 1980)



items

- PBC

PB01_33 Die Anschaffung einer Photovoltaikanlage liegt ganz bei mir.
PB01_29 Es liegt ganz bei mir eine Photovoltaikanlage für mein Haus oder meine Wohnung anzuschaffen.
PB01_32 Die Anschaffung eines Batteriespeichers liegt ganz bei mir.
PB01_31 Ich habe die volle Kontrolle darüber, ob ich mir eine Photovoltaikanlage anlege oder nicht.
PB01_30 Ich habe die volle Kontrolle darüber, ob ich mir einen Batteriespeicher anschaffe oder nicht.

Integrated model