Die Rolle emotionaler Kohärenz für gesellschaftliche Transformationsprozesse

Dissertation

Zur Erlangung des akademischen Grades

Doktor der Philosophie (Dr. Phil.)

am Fachbereich Erziehungswissenschaften und Psychologie

der Freien Universität Berlin

Vorgelegt von

Ingo Wolf, Dipl. Psych.

Berlin, 2021

Erstgutachter:

Prof. Dr. Gerhard de Haan (Freie Universität Berlin)

Zweitgutachter:

Prof. Dr. Tobias Schröder (Fachhochschule Potsdam)

Tag der Disputation:

02. Mai 2022

Danksagung

Die vorliegende Arbeit wäre ohne die Hilfe und Unterstützung zahlreicher Personen nicht möglich gewesen. Bei ihnen möchte ich mich an dieser Stelle von ganzem Herzen bedanken.

Mein ganz besonderer Dank gilt Gerhard de Haan, der die Realisierung dieses Forschungsvorhabens durch meine Tätigkeit in den Drittmittelprojekten INNO-SIM und MonForSense überhaupt erst ermöglichte. Seine Geduld und Offenheit für neue Themen sowie sein Vertrauen in mich haben mir geholfen, das Ziel letztendlich nicht aus den Augen zu verlieren. Vielen Dank für die Bereitstellung der sehr angenehmen und anregenden Arbeitsatmosphäre am Institut Futur.

Weiterhin danke ich herzlich Tobias Schröder für seine vielfältige und stetige Unterstützung sowohl bei diversen wissenschaftlichen Fragen als auch als Mentor dieser Arbeit. Die zahlreichen Diskussionen, Kommentare und Ideen bei den unterschiedlichen Etappen dieser Arbeit habe ich als sehr hilfreich und motivierend empfunden. Er war für mich während der gesamten Zeit eine wesentliche Stütze sowohl in menschlicher als auch in fachlicher Hinsicht.

Darüber hinaus möchte ich meinen Kolleginnen und Kollegen am Institut Futur und FH Potsdam meine Wertschätzung ausdrücken. Besonders erwähnen möchte ich meine unmittelbaren Projektmitarbeiterinnen und -mitarbeiter: Jochen Neumann, Jakob Dordevic, Alexander Hatri, Kerstin Stark, Alice Bobée, Vera Röhr, Nikolas Zöller und Christian Mosau. Vielen Dank für eure Unterstützung, die wissenschaftlichen Diskussionen und unschätzbare Hilfe bei der Konzeption des Fragebogens und Vignettenexperiments, Datenerhebung und -auswertung, Programmierung und diversen anderen Tätigkeiten.

Dem Bundesministerium für Bildung und Forschung (BMBF) möchte ich für die finanzielle Unterstützung danken.

Schließlich möchte ich mich bei meiner Frau Anja und meinem Sohn Jonah für ihre Geduld, Unterstützung und Ermutigungen bedanken. Sie haben mir die vielen zeitlichen Freiräume geschaffen, um die Arbeit voranzubringen.

Zusammenfassung

Die Verkehrswende, der Umbau des Verkehrssystems hin zu einer ökologisch nachhaltigen Mobilität, ist ein komplexer gesellschaftlicher Transformationsprozess. Der Wandel erfordert, neben der Schaffung entsprechender politischer Rahmenbedingungen und dem Einsatz neuer Technologien, tiefgreifende Änderungen von Einstellungen und Verhaltensweisen sowie kulturell geprägter Deutungsmuster in der Gesellschaft. Unter welchen Bedingungen sich derartige Veränderungen auf der Ebene des Individuums und auf der Ebene sozialer Strukturen ergeben können und wie diese Ebenen miteinander wechselwirken, ist jedoch nicht ausreichend erforscht. Ziel dieser kumulativen Dissertation ist es, auf theoretischer sowie empirischer Basis ein agentenbasiertes Modell der Einstellungs- und Entscheidungsänderungen der Verkehrsmittelwahl zu schaffen. Ich beziehe mich dabei auf die kognitionswissenschaftliche Forschung zur Rolle von Emotionen bei der Informationsverarbeitung und Entscheidungsfindung, auf Forschungsarbeiten zu der Wirkung sozialer Einflüsse aus den Bereichen der Sozialpsychologie und Soziologie sowie auf die umweltpsychologische Forschung zur Segmentierung von Zielgruppen.

In Studie 1 wurde anhand eines Vignettenexperiments und eines kognitiv-affektiven Modells dyadischer Kommunikation untersucht, welchen Einfluss die Verwendung emotionaler Sprache im Zuge persuasiver Kommunikation auf die Informationsverarbeitung von Menschen hat. Die Ergebnisse zeigen, dass die Tendenz zur motivierten Informationsverarbeitung (motivierte Kognition) durch die Valenz und den Grad der Emotionalität in der Kommunikation beeinflusst wird. Mithilfe des Modells können die beobachteten Effekte durch den Mechanismus der emotionalen Kohärenz erklärt und in ihrer Wirkung auf mentale Strukturen geschätzt werden.

In Studie 2 wurden die Einstellungen und affektiven Bedeutungen einer breiten Palette von konventionellen und neueren Verkehrsmitteln untersucht. Auf Basis der affektiven Wahrnehmungen konnten unterschiedliche Mobilitätstypen identifiziert werden. Darüber hinaus zeigt die Studie, dass die typspezifischen affektiven Bedeutungsmuster die Bereitschaft, emissionsarme Verkehrsmittel zu nutzen, im hohen Maße bestimmen.

In Studie 3 wurden die theoretischen und empirischen Ergebnisse aus den vorangegangenen Studien in dem agentenbasierten Modell *InnoMind* (**Inno**vation diffusion driven by changing **Mind**s) zusammengeführt. Die Simulationsszenarien zu unterschiedlichen Fördermaßnahmen von Elektromobilität verdeutlichen, dass die Wirksamkeit der Instrumente durch die zielgruppenspezifischen Einstellungsmuster und sozialen Interaktionen der Verkehrsteilnehmerinnen und Verkehrsteilnehmer beeinflusst werden.

In Studie 4 wurde das Modell *InnoMind* genutzt, um die einstellungsverändernden Effekte von Informationskampagnen zur Nutzung von Carsharing zu untersuchen. Das Vorgehen verdeutlicht die Flexibilität und Adaptivität des Simulationsansatzes. Darüber hinaus zeigt die Studie, dass die veränderte Darstellung der Mobilitätsoptionen in den Kampagnen deren Wirkung in bedeutsamen Maß beeinflussen kann.

Insgesamt unterstreichen die Ergebnisse die Bedeutung affektiv-emotionaler Prozesse für die Einstellungsbildung und -änderung. Die Verarbeitung von (sozialen) Informationen unterliegt Verzerrungen, die zu einer Konstruktion einer konsistenten Repräsentation bestehender Überzeugungen und Emotionen führen. Diese auf individueller Ebene wirkenden Mechanismen haben in Wechselwirkung mit sozialen Kommunikationsprozessen und Informationsflüssen einen entscheidenden Einfluss auf die Dynamiken im Zuge gesellschaftlicher Transformationen.

Das in dieser Arbeit entwickelte agentenbasierte Modell ermöglicht es, derartige komplexe Interaktionsprozesse und Dynamiken zu analysieren. Auf der Grundlage kognitionswissenschaftlicher, sozialpsychologischer und soziologischer Theorien sowie umfassender Empirie erweitert es die bisherige Forschung zu Meinungsdynamiken und sozialen Einflüssen mithilfe sozialer Simulationen. Zudem vermittelt das Modell handlungsrelevantes Wissen, um die Akzeptanz der Verkehrswende in der Gesellschaft zu fördern.

Schlagwörter: Einstellungen, affektive Bedeutungen, emotionale Kohärenz, sozialer Einfluss, agentenbasierte Modellierung, motivierte Kognition, Typenbildung, Verkehrswende

Summary

The transformation of the transport system toward ecologically sustainable mobility is a complex social transition process. In addition to the creation of appropriate political framework conditions and the use of new technologies, the transformation requires profound changes in attitudes and behaviors as well as culturally shaped patterns of meanings in society. However, the conditions under which such changes might occur at the individual and at the level of social structures, and how these levels interact with each other, have not been sufficiently investigated. The aim of this cumulative dissertation is to create an agent-based model of attitudinal and decision-making changes in transportation choice on a theoretical as well as empirical basis. I draw on cognitive science research on the role of emotions in information processing and decision making, research on the effect of social influence from the fields of social psychology and sociology, and environmental psychology research on target group segmentation.

In study 1, a vignette experiment and a cognitive-affective model of dyadic communication were used to investigate the influence of the use of emotional language in the course of persuasive communication on people's information processing. The results show that the tendency towards motivated information processing (motivated cognition) is influenced by the valence and the degree of emotionality in the communication. Using the model, the observed effects can be explained by the mechanism of emotional coherence and estimated in terms of their effect on mental structures.

Study 2 examined the attitudes and affective meanings of a wide range of conventional and newer modes of transportation. Based on the affective perceptions, different mobility types could be identified. Furthermore, the study shows that the type-specific affective meaning patterns determine the willingness to use low-emission transport modes to a high degree.

In study 3, the theoretical and empirical results from the previous studies were combined in the agent-based model *InnoMind* (Innovation diffusion driven by changing Minds). The simulation scenarios for different measures promoting electric mobility illustrate that the effectiveness of the instruments is influenced by the target group-specific attitude patterns and social interactions of the road users.

In study 4, the *InnoMind* model was used to investigate the attitude-changing effects of information campaigns on the use of car sharing. The approach illustrates the flexibility and adaptivity of the simulation approach. Furthermore, the study shows that the altered presentation of mobility options in the campaigns can influence their impact to a significant degree.

Overall, the results underline the importance of affective-emotional processes for attitude formation and change. The processing of (social) information is subject to distortions that lead to the construction of a consistent representation of existing beliefs and emotions. These mechanisms, acting on an individual level, interact with social communication processes and information flows to have a decisive influence on the dynamics in the course of social transformations.

The agent-based model developed in this thesis makes it possible to analyze such complex interaction processes and dynamics. Based on cognitive science, social psychology, and sociological theories as well as extensive empirical evidence, it extends previous research on opinion dynamics and social influence by means of social simulations. In addition, the model provides actionable knowledge to promote the acceptance of the transport transition in society.

Keywords: Attitudes, affective meanings, emotional coherence, social influence, agent-based modeling, motivated cognition, segmentation, transport transition

Abkürzungsverzeichnis

ABC	*Adaptive Behavior and Cognition*
ABM	*agentenbasierte Modellierung*
ACS	*Attitudes as Constraint Satisfaction*
AG	*Aktiengesellschaft*
BMBF	*Bundesministerium für Bildung und Forschung*
BMUB	*Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit*
BMVBS	*Bundesministerium für Verkehr, Bau und Stadtentwicklung*
ECHO	*Explanatory Coherence*
HOTCO	*Hot Coherence*
ICE	*Internal combustion engine*
InnoMind	*Innovation diffusion by changing minds*
PCS	*Parallel Constraint Satisfaction*
UBA	*Umweltbundesamt*

Inhaltsverzeichnis

1 EINLEITUNG **10**

2 KONZEPTIONELLE UND THEORETISCHE GRUNDLAGEN **13**

2.1 Entscheidungen und Einstellungen 13
2.2 Sozialer Einfluss 20
2.3 Typenbildung und Segmentierung 25

3 FORSCHUNGSFRAGEN **28**

4 METHODISCHES VORGEHEN **31**

5 STUDIE 1 – MIKROEBENE: THE CRITICAL ROLE OF EMOTIONAL COMMUNICATION FOR MOTIVATED REASONING **36**

6 STUDIE 2 – MESOEBENE: CONNOTATIVE MEANINGS OF SUSTAINABLE MOBILITY: A SEGMENTATION APPROACH USING CULTURAL SENTIMENTS **57**

7 STUDIE 3 - MAKROEBENE: CHANGING MINDS ABOUT ELECTRIC CARS: AN EMPIRICALLY GROUNDED AGENT-BASED MODELING APPROACH **99**

8 STUDIE 4– MAKROBENE: MODELING MULTI-LEVEL MECHANISMS OF ENVIRONMENTAL ATTITUDES AND BEHAVIOURS: THE EXAMPLE OF CARSHARING IN BERLIN **132**

9 ALLGEMEINE DISKUSSION UND AUSBLICK **164**

9.1 Diskussion der Forschungsfragen 164
9.2 Einschränkungen und offene Fragen 175
9.3 Implikationen und Perspektiven für Forschung und Praxis und Ausblick 180

LITERATURVERZEICHNIS **182**

EIDESSTATTLICHE ERKLÄRUNG **196**

ABBILDUNGSVERZEICHNIS **197**

TABELLENVERZEICHNIS **198**

1 Einleitung

Die Bedeutung des Verkehrssektors für die Eindämmung des Klimawandels wird zunehmend deutlicher (z. B. Sims et al., 2014). In Deutschland war dieser Sektor im Jahr 2018 mit 19 % der drittgrößte Verursacher von klima- und gesundheitsschädlichen Emissionen (UBA, 2020). Trotz diverser politischer Anstrengungen und einer Vielzahl technischer Neuerungen im Fahrzeugbereich sind in den letzten Jahren die Treibhausgasemissionen im Vergleich zu 1990 weiter gestiegen (BMUB, 2017). Setzt sich dieser Trend fort, wird Deutschland den im Weltklimavertrag von Paris anvisierten Beitrag zur Emissionsreduktion von Treibhausgasen und die nationalen Klimaschutzziele nicht erreichen können.

Eine ökologische Verkehrswende mit dem Ziel einer vollständigen Dekarbonisierung des Personen- und Güterverkehrs bedarf technologischer Innovationen (z. B. Elektrofahrzeuge mit Strom aus erneuerbaren Energien), neuer Verkehrskonzepte (z. B. Shared-Mobility, Stadt der kurzen Wege) sowie gezielter regulatorischer Maßnahmen und Interventionen (z. B. Innenstadtmaut) (vgl. Agora Verkehrswende, 2017). Der Erfolg dieser umfassenden Transformation des Verkehrssektors hängt jedoch auch von einem dauerhaften Werte-, Einstellungs- und Verhaltenswandel in der Bevölkerung ab (Brien, 2015; Creutzig et al., 2015; Steg, Perlaviciute, & van der Werff, 2015).

Die zentralen Fragen dabei sind: Unter welchen politischen und gesellschaftlichen (Rahmen-)Bedingungen kann und wird sich eine neue Mobilitätskultur etablieren? Welche politischen Maßnahmen und Interventionen sind am effektivsten, um Einstellungen und Verhalten zu verändern? Erfüllen die neuen Angebote die unterschiedlichen und vielfältigen Mobilitätsbedürfnisse einer hochmobilen Gesellschaft? Sind die Menschen bereit und in der Lage, ihre Einstellungen, Gewohnheiten und Verhaltensweisen im Sinne einer nachhaltigen Mobilität zu ändern?

Im Bereich der Verkehrsforschung werden zur Beantwortung derartiger Fragen häufig sogenannte integrierte Bewertungsmodelle (IBM) verwendet (vgl. McCollum et al., 2016). Ihr Zweck ist es, Erkenntnisse über die systemischen Folgen techno-ökonomischer Entwicklungen sowie bestimmter Technologie- und Politikentscheidungen zu generieren. Die Darstellung von nationalen bis globalen Verkehrs- oder Energiesystemen in solchen Modellen ist zwangsläufig stilisiert, vereinfacht und selektiv. Dies trifft im Besonderen auf die Repräsentation von menschlichen Entscheidungen und Verhaltensweisen zu, die in der Regel – wenn überhaupt – in Form eines einzelnen, unabhängig und vollständig rational handelnden „repräsentativen Agenten" beschrieben werden (vgl. Moss et al., 2010). Die Plausibilität und Richtigkeit der damit verbundenen Grundannahmen, wie beispielsweise zeitlich stabile und vom (sozialen) Umfeld unabhängige Präferenzen, eine nutzenmaximierende Auswahl von Handlungsoptionen oder die Verfügbarkeit vollständiger Informationen über alle

Handlungsoptionen, sind jedoch durch eine Vielzahl theoretischer und empirischer Arbeiten der Entscheidungsforschung widerlegt worden (Gigerenzer & Goldstein, 1996; Metcalfe & Dolan, 2012; Herbert A. Simon, 2000; Tversky & Kahneman, 1981).

Die Ergebnisse aktueller IBM-Studien zur Transformation von Energie- und Verkehrssystemen legen nahe, dass diese unrealistischen Annahmen über menschliches Entscheidungsverhalten einen erheblichen Einfluss auf (politisch relevante) Resultate und daraus abgeleitete Implikationen haben (z. B. McCollum et al., 2018; Mercure, Pollitt, Bassi, Viñuales, & Edwards, 2016; Steg et al., 2015). Psychologische Forschungen zu nachhaltigen Verhalten in den Bereichen Mobilität und Energie zeigen zudem, dass neben den instrumentellen Aspekten wie Kosten und Zeit auch affektive und soziale Motive bei der Gestaltung effektiver politischer Instrumente berücksichtigt werden müssen (z. B. Steg et al., 2015). Die Integration psychologischer und soziologischer Dimensionen in formalisierte Modelle sozio-technischer Systeme ist folglich von zentraler Bedeutung, um das Verständnis über die Hemmnisse und Gelingensfaktoren gesellschaftlicher Transformationen zu verbessern (Conte & Giardini, 2016; Rai & Henry, 2016; Squazzoni, 2017).

Das Ziel der vorliegenden Dissertation ist es, einen Beitrag zu dieser Forschungslücke zu leisten. Konkret richtet sich das Forschungsinteresse auf die Konzeption und Umsetzung eines neuen mathematisch formalisierten Ansatzes zur Untersuchung psychologischer und sozialer Aspekte einer ökologisch nachhaltigen Mobilitätswende. Das Hauptaugenmerk liegt dabei auf den affektiv-emotionalen sowie sozialen Einflüssen menschlicher Einstellungen und Entscheidungen gegenüber neuen Formen der Mobilität. Auf der Grundlage kognitionswissenschaftlicher, sozialpsychologischer und soziologischer Theorien sowie empirischer Untersuchungen ist ein neues agentenbasiertes Modell namens *InnoMind* entwickelt worden. Das Modell dient einerseits theoretischen Analysen der aus dem Zusammenwirken individueller, sozialer und politischer Einflussfaktoren entstehenden Dynamiken von Einstellungen und menschlichem Verhalten. Andererseits soll damit ein anwendungsorientierter Beitrag zu einem besseren Verständnis über die Merkmale, Hemmnisse und Treiber einer gesellschaftlichen Transformation im Verkehrsbereich geleistet werden.

Aufbau der Dissertation

Die Dissertationsschrift ist als eine kumulative Arbeit verfasst[1]. Sie umfasst ein Rahmendokument und vier Forschungsartikel, von denen bereits drei in begutachteten Fachzeitschriften veröffentlicht wurden. Zu Beginn der Arbeit werden in Kapitel 2 die konzeptionellen und theoretischen Grundlagen dargestellt, die für die einzelnen (empirischen) Studien herangezogen wurden. Dieser Teil

[1] Die Forschungsartikel sind in englischer Sprache verfasst.

umfasst einen literarischen Überblick über die im Kontext der Arbeit relevanten Konzepte und Forschungsergebnisse. Jedes Thema wird in einem eigenen Unterkapitel beleuchtet und Forschungslücken werden identifiziert.

In Kapitel 3 werden die Forschungsziele und -fragen der Studien erläutert, bevor im anschließenden Kapitel 4 die Methodenauswahl vorgestellt und begründet wird. Ausgehend von den in der Literaturübersicht dargelegten Konzepten werden die Operationalisierung und das methodische Vorgehen in den empirischen Untersuchungen beschrieben.

In den folgenden Kapiteln 5 bis 7 werden die vier Studien beziehungsweise Forschungsartikel vorgestellt. Im ersten Artikel „The critical role of emotional communication for motivated reasoning" werden die Ergebnisse aus einer experimentellen Untersuchung und deren modellbasierten Umsetzung zu den Effekten persuasiver Kommunikation beschrieben (Kapitel 5). Die dort vorgeschlagene Modellierung von Einstellungen und Entscheidungen sowie die identifizierten Modellparameter stellen die zentralen Elemente des im dritten und vierten Artikel präsentierten agentenbasierten Modells *InnoMind* dar. Der zweite Artikel „Connotative meanings of sustainable mobility: A segmentation approach using cultural sentiments" erläutert die Ergebnisse einer deutschlandweiten Befragungsstudie zu den Einstellungen und (affektiven) Bewertungen neuer Mobilitätsformen (Kapitel 6). Zudem wird ein neuer, im Rahmen der Untersuchung entwickelter Zielgruppenansatz für Mobilitätsinnovationen vorgestellt. Der dritte Artikel „Changing minds about electric cars: An empiricallly grounded agent-based modeling apporach" und der vierte Aufsatz „Modeling multi-level mechanisms of environmental attitudes and behaviors: The example of carsharing in Berlin" beschreiben das agentenbasierte Modell *InnoMind* sowie die zentralen Erkenntnisse, die aus den durchgeführten Simulationen zu unterschiedlichen Mobilitätsinnovationen sowie (politischen) Interventionen gewonnen werden konnten (Kapitel 7 & 8).

Schließlich werden in Kapitel 9 die zentralen Ergebnisse der Arbeit und das entwickelte Verfahren kritisch diskutiert. Die Arbeite endet mit den Implikationen und dem Ausblick weiteres Forschungspotenzial in dem Themenfeld.

2 Konzeptionelle und theoretische Grundlagen

Im folgenden Kapitel wird die konzeptionelle und theoretische Basis der Forschungsarbeit vorgestellt. Zunächst erfolgt ein Überblick über die für die Arbeit relevanten Theorien und Modelle der Entscheidungsforschung und Einstellungsbildung, wobei der Schwerpunkt auf den Theorien der psychologischen Konsistenzforschung liegt. Anschließend werden die zentralen Theorien sozialer Beeinflussung sowie theoretische Modelle sozialer Netzwerke betrachtet. Der Fokus liegt dabei auf formalisierten Ansätzen, auf deren Grundlage soziale Dynamiken in Gruppen, Organisationen und ganzen Gesellschaften mittels der Methode der agentenbasierten Modellierung (ABM) untersucht wurden. Das letzte Unterkapitel widmet sich unterschiedlichen sozialwissenschaftlichen Ansätzen der Zielgruppenbildung im Verkehrsbereich. Jeder Abschnitt wird im Rahmen einer Zusammenfassung durch die Darstellung der wesentlichen Forschungslücken abgerundet.

2.1 Entscheidungen und Einstellungen

Die Frage, wie Menschen Entscheidungen treffen, ist seit vielen Jahrzehnten Gegenstand wissenschaftlicher Forschung. In den frühen Arbeiten wurden unter dem Begriff *Entscheidung* der Moment oder das Ergebnis einer Auswahl zwischen mindestens zwei Optionen verstanden. Theorien der Entscheidungsfindung aus dieser Zeit waren noch relativ allgemein formuliert und zielten nicht darauf ab, die einer Entscheidung zugrunde liegenden Prozesse zu beschreiben, sondern vielmehr deren Ergebnis vorherzusagen. Der Fokus der Forschung lag dabei auf den kognitiven Aspekten, während emotionale Einflüsse auf Entscheidungen größtenteils keine Beachtung fanden (siehe Loewenstein & Lerner, 2003). Das wohl bekannteste Beispiel in dieser Kategorie ist das aus der Ökonomie stammende Modell des *erwarteten Nutzens* oder auch *Nutzenmaximierungsmodell* (Savage, 1954; von Neumann & Morgenstern, 1944). Die Theorie geht davon aus, dass Menschen den subjektiven Nutzen von Handlungsoptionen bewusst bewerten und in einer gegebenen Entscheidungssituation rational die Alternative auswählen, die den maximalen (ökonomischen) Nutzen verspricht.

Die rationale Entscheidungstheorie findet bis heute in unterschiedlichen Handlungsfeldern vielfach Anwendung und beeinflusst(e) theoretische wie auch empirische Forschungsarbeiten in diversen Disziplinen. Die Arbeiten verdeutlichten jedoch auch, dass menschliches Entscheidungsverhalten mit diesem Modell in vielen Situationen nur unzureichend erklärt werden kann und diverse empirische Befunde im Widerspruch zu den Grundannahmen der Theorie stehen (vgl. Harless & Camerer, 1994; Kahneman & Tversky, 1979; Mullainathan & Thaler, 2000). Als einer der ersten Wissenschaftler stellte in diesem Zusammenhang Herbert A. Simon (1955, 1982) die bei dem Nutzenmaximierungsmodell angenommenen komplexen Berechnungsprozesse während der Entscheidungshandlungen infrage. Er wies darauf hin, dass Entscheider:innen aufgrund begrenzter zeitlicher und kognitiver Ressourcen den Anforderungen des Modells nicht genügen können. Mit dem von ihm eingeführten Konzept der *bounded rationality* (eingeschränkten Rationalität) wurde der Grundstein für eine Vielzahl von Theorien des Entscheidens und Urteilens gesetzt, deren Aufmerksamkeit insbesondere auf die psychologischen Mechanismen und Prozesse der Informationsverarbeitung und Entscheidungsfindung gerichtet ist.

Im Zuge dieser Entwicklung hat sich auch der Entscheidungsbegriff erweitert. Entscheidungen wurden zunehmend, so auch in dieser Arbeit, als *mentaler Prozess* verstanden, dessen zentrale Komponenten Gefühle und Emotionen, Überzeugungen, Ziele und Entscheidungsoptionen sind. Mentale Prozesse können auf einem Kontinuum von automatisch-unbewusst und kontrolliert-bewusst eingeordnet werden. Aus analytischen Gründen wurde eine Reihe sogenannter dualer Prozessmodelle *oder Zwei-System-Modelle* vorgeschlagen, die das Kontinuum in zwei qualitativ unterschiedliche Subsysteme beziehungsweise Gruppen von Prozessen unterteilen (z. B. Chaiken & Trope, 1999; Kahneman, 2003; 2011; Stanovich & West, 2003): System 1 basiert auf einer intuitiven, automatischen Verarbeitung. Informationen werden dort relativ schnell und parallel verarbeitet; die Verarbeitung erfolgt assoziativ, ohne Anstrengung und umfasst sowohl affektive als auch kognitive Prozesse. Im Gegensatz dazu basiert System 2 auf einer reflektierten, bewussten Verarbeitung, bei der Informationen kontrolliert, intentional und schrittweise verarbeitet werden. Es bedarf hierzu einer gezielten Aufmerksamkeitsallokation und einer kognitiven Anstrengung.

Ausgehend von den durch Simon (1955) identifizierten Kapazitätsgrenzen des kontrolliert-bewussten Systems (System 2) haben sich im Wesentlichen zwei Forschungsansätze entwickelt. Der erste Ansatz geht davon aus, dass Entscheidungen auf situationsspezifischen einfachen Strategien, sogenannten *Heuristiken*, beruhen (Gerd Gigerenzer & Gaissmaier, 2011; Tversky & Kahneman, 1974). Diese einfachen nichtkompensatorischen Regeln erfordern keine Berechnung des optionalen Nutzens und reduzieren somit die für die Entscheidung benötigte Informationsmenge und die damit verbundene Anzahl kognitiver Operationen. Heuristiken werden sowohl unbewusst (System 1) als auch bewusst (System 2) ausgewählt und je nach Situation adaptiv angewandt (Gigerenzer, 2004; Kahneman, 2003; Payne, Bettman, & Johnson, 1988). Sie sind typischerweise domänenspezifisch, sodass mittlerweile eine große Vielzahl derartiger Strategien vorgeschlagen wurde (vgl. Kahnemann, 2011). Trotz einiger Versuche (z. B. Gigerenzer, Todd, & ABC Research Group, 1999; Gerd Gigerenzer & Gaissmaier, 2011; Shah & Oppenheimer, 2008) ist es bislang noch nicht gelungen, diese Entscheidungsregeln zu einer integrierten Theorie der Heuristik zusammenzuführen.

Theorien, die dem zweiten Ansatz zuzuordnen sind, stellen den offensichtlich begrenzten Kapazitäten des kontrolliert-bewussten kognitiven Systems (System 2) die umfassende Leistungsfähigkeit des automatisch-unbewussten Systems (System 1) gegenüber. Letzteres, so die Annahme, befähigt Menschen dazu, eine Vielzahl von Informationen parallel und kompensatorisch zu verarbeiten. Trotz der spezifischen Strukturen und Schwerpunktsetzungen der einzelnen Modelle liegt das Hauptaugenmerk dieser kognitionspsychologischen Ansätze auf den *affektiv-kognitiven Mechanismen* der Informationsverarbeitung und Entscheidungsfindung (für einen Überblick siehe Lerner, Li, Valdesolo, & Kassam, 2015; Oppenheimer & Kelso, 2015). Entscheidungen werden nach diesem Verständnis als komplexe, weitestgehend automatisch ablaufende Prozesse verstanden, die auf den elementaren Mechanismen der Wahrnehmung (z. B. McClelland & Rumelhart, 1981), der Aufmerksamkeit (z. B. Krajbich, Lu, Camerer, & Rangel, 2012), der Gedächtnisbildung und des -abrufs (z. B. Johnson, Häubl, & Keinan, 2007) sowie auf affektiven und emotionalen Reaktionen basieren (z. B. Volz & Hertwig, 2016). Die Encodierung, also die Verarbeitung externer Informationen und die Erzeugung mentaler Repräsentationen, erfolgt demnach ohne bewusste Kontrolle und unter Aktivierung bestehenden Wissens aus dem Gedächtnis. Dabei werden vorhandene Informationen selektiert, auf Basis von verfügbaren Schemata und Kategorien eingeordnet und mentale Repräsentationen werden angepasst oder neu gebildet (vgl. Pfister, Jungermann, & Fischer, 2017).

Auch die aktuellen theoretischen Ansätze der Einstellungsforschung unterscheiden sich hinsichtlich der Frage, inwieweit *Einstellungen* explizite, stabile, im Gedächtnis gespeicherte Entitäten oder vorübergehende implizite Urteile sind, die aus den zu einem bestimmten Zeitpunkt vorliegenden Informationen gebildet werden (vgl. Bohner & Dickel, 2011). Ein Großteil der Forschung in diesem Bereich beruht auf dem dreigliedrigen Modell von Einstellungen, das davon ausgeht, dass Einstellungen aus affektiven, kognitiven sowie verhaltensbezogenen (konativen) Komponenten bestehen (Fishbein & Ajzen, 1975; Rosenberg, Hovland, McGuire, Abelson, & Brehm, 1960). Die Integration der Verhaltenskomponente in das Konzept der Einstellung ist jedoch vielfach kritisiert worden, unter anderem weil damit Widersprüche zwischen Einstellungen und Verhalten nicht schlüssig erklärt werden können (vgl. Cacioppo, Petty, & Green, 1989; Fazio & Olson, 2003). Folglich hat sich in jüngerer Zeit eine reduzierte Einstellungsdefinition durchgesetzt, bei der Einstellungen als Bewertungen und somit als affektive Reaktionen gegenüber einem Einstellungsobjekt (z. B. Person, Verhaltensweise, Gegenstand) verstanden werden (Banaji & Heiphetz, 2010). Der Schwerpunkt der Arbeiten im Bereich der Einstellungsforschung hat sich dabei in den letzten Jahren auf die ganzheitliche Betrachtung von Einstellungsbildung- und -veränderungen in persönlichen, sozialen und historischen Kontexten fokussiert (vgl. Albarracin & Shavitt, 2018) und erste allgemeine formalisierte Einstellungsmodelle hervorgebracht (Dalege et al., 2015; Monroe & Read, 2008).

Kohärenzbasierte Modelle

Kohärenzbasierte Modelle spielen bei der Entwicklung integrierter und mathematisch formalisierter Einstellungs- und Entscheidungstheorien eine zunehmend bedeutende Rolle (Glöckner & Betsch, 2008; Holyoak & Powell, 2016; Monroe & Read, 2008; Read & Simon, 2012). Gemeinsames Merkmal der Modelle, die diesem Ansatz zugeordnet werden, ist die Betonung des konstruktiven Charakters von Entscheidungsprozessen und Einstellungsbildung. Demnach werden (neue) Informationen nicht nur mit bestehenden Repräsentationen im Gedächtnis abgeglichen. Vielmehr werden mentale Repräsentationen durch kohärenzgeleitete Prozesse konstruiert, die über die Akkumulation verfügbarer Evidenz hinausgeht. Informationen werden dabei potenziell modifiziert, verzerrt und Elemente werden neu kombiniert, sodass eine konsistente und widerspruchsfreie Gesamtinterpretation gegebener Informationselemente möglich wird (McClelland & Rumelhart, 1981; Read, Vanman, & Miller, 1997). Entscheidungen oder Urteile werden nach dieser Auffassung unter Rückgriff sowohl automatisch-unbewusster als auch kontrolliert-bewusster Teilprozesse getroffen (Betsch & Glöckner, 2010; Glöckner & Witteman, 2010). Kohärenzbasierte Verzerrungseffekte konnten bei einer Vielzahl von Entscheidungsaufgaben gezeigt werden, so zum Beispiel bei rechtlichen Entscheidungen (Simon, Snow, & Read, 2004), Präferenzentscheidungen (Simon, Krawczyk, Bleicher, & Holyoak, 2008) oder probabilistischen Urteilen (Gloeckner, Betsch, & Schindler, 2010). Zudem stützen die umfassenden Arbeiten zu prädezisionalen Informationsverzerrungen die Annahme, dass es sich hierbei um einen zentralen Mechanismus von Entscheidungsprozessen handelt (Brownstein, 2003; DeKay, Miller, Schley, & Erford, 2014; Russo, Carlson, Meloy, & Yong, 2008).

Kohärenzbasierte Einstellungs- und Entscheidungsmodelle gehen auf zwei bedeutsame Ansätze der Konsistenzforschung zurück, nämlich den der kognitiven Konsistenztheorien und der Gestaltpsychologie (vgl. Read et al., 1997). Zu den wichtigsten Vertretern der Konsistenztheorien zählen die Balance-Theorie von Heider (1946, 1958), die Theorie der kognitiven Dissonanz von Festinger (1957), die Kongruenztheorie von Osgood & Tannenbaum (1955). Im Mittelpunkt dieser kognitionspsychologischen Ansätze stehen die zentralen Prinzipien der gestaltpsychologischen Lehre (Asch, 1946; Wertheimer, 1923). Demnach sind mentale Repräsentationen als ganzheitliche Konstrukte zu verstehen, die durch die Struktur und Interaktion ihrer konstituierenden Elemente entstehen beziehungsweise bestimmt werden. Diese Strukturen sind dynamisch und besitzen durch Wechselwirkungen das Potenzial für strukturelle Veränderungen. Dabei haben die dynamischen psychischen Prozesse die Tendenz zur „guten Gestalt", die eine Symmetrie, Geschlossenheit und Konsistenz mentaler Strukturen und gegebener Informationen erzeugt (vgl. Metzgrer, 1966). Inkonsistente mentale Zustände erzeugen hingegen Veränderungskräfte, die zur Wiederherstellung der inneren Kohärenz beitragen (Heider, 1958). Dieser Gleichgewichtszustand wird durch Veränderungen oder Rekonstruktionen der kognitiven Elemente einer mentalen Repräsentation erreicht (Abelson & Rosenberg, 1958; Asch, 1946; Festinger, 1957). Trotz der verschiedenen Anwendungsbereiche der einzelnen Konsistenztheorien stellt das Streben nach Maximierung der Konsistenz mentaler Strukturen beziehungsweise die Vermeidung von Inkonsistenzen durch die dynamische Neuanordnung und Modifikation mentaler Strukturen das gemeinsame Kernelement dieser Modelle dar (für eine Übersicht siehe Harmon-Jones & Mills, 1999; Simon & Holyoak, 2002).

Die frühen Konsistenztheorien waren jedoch nicht in der Lage, komplexe mentale Repräsentationen sowie deren inhaltliche Bedeutungen und dynamische Interaktionen abzubilden. Zudem wurde von einigen Forschern das Fehlen eines formalisierten Modells zu Bewertung und Berechnung der Konsistenz kritisiert (Read et al., 1997; Read & Monroe, 1994). Die entscheidende Weiterentwicklung stellte das Aufkommen der *konnektionistischen Theorien* beziehungsweise der hierzu gehörenden sogenannten *Parallel-Constraint-Satisfaction (PCS) Modelle* dar (z. B. Holyoak & Thagard, 1989; McClelland & Rumelhart, 1986; Rumelhart & McClelland, 1986; Thagard, 1989). Konnektionistische Modelle ermöglichen es, die aus den Konsistenz- und Gestalttheorien stammenden Prinzipien und Strukturen von einfachen auf komplexe Konstellationen mentaler Konzepte zu erweitern. Zudem wurde durch die Formalisierung des vormals unscharfen Konzepts der Konsistenz in PCS-Modellen Kohärenz messbar und mathematisch exakt definiert (Hopfield, 1982; Rumelhart, Smolensky, McClelland, & Hinton, 1986; Thagard & Verbeurgt, 1998).

In PCS-Modellen wird die Informationsverarbeitung des menschlichen Gehirns als parallele Signalverbreitung mittels künstlicher neuronaler Netzwerke repräsentiert. Die für eine bestimmte mentale Aufgabe (z. B. Entscheidung) relevanten Konzepte (z. B. Ziele, Handlungsoptionen) werden als einzelne Elemente, sogenannte Knoten oder Units, dargestellt. Diese sind untereinander über exzitatorische oder inhibitorische Verbindungen verknüpft, womit entweder positive (z. B. bei zusammengehörigen, sich unterstützenden Konzepten) beziehungsweise negative (z. B. bei nicht zusammengehörigen, widersprüchlichen Konzepten) Beziehungen zwischen den Konzepten symbolisiert werden, sogenannte einschränkende Bedingungen (constraints). Die Verbindungen können in ihrer Stärke variieren, abhängig von der inhaltlichen Beziehung zwischen den jeweiligen Elementen. Durch die Initialisierung des PCS-Algorithmus erfolgt eine parallele Ausbreitung der Signale (Aktivierungen) im Netzwerk, wobei sich die miteinander verbundenen Konten wechselseitig aktivieren beziehungsweise beeinflussen. Knoten, die durch exzitatorische Verbindungen miteinander verbunden sind, erreichen somit hohe positive Aktivierungswerte und reduzieren dadurch gleichzeitig die Aktivierungen der Elemente, die durch negative, inhibitorische Links verbunden sind. Umgekehrt gilt dies auch für inhibitorisch verbundene Elemente. Im Ergebnis der iterativen Wiederholung dieses Prozesses nähern sich Aktivierungen im Netzwerk an und konvergieren zu einem stabilen Muster, unter dem die parallel wirksamen einschränkenden Bedingungen der Entscheidung am besten erfüllt sind (*parallel constraint satisfaction*; Rumelhart, Smolensky, McClelland, & Hinton, 1986). Bei einer Entscheidung über zwei Handlungsoptionen haben sich zu diesem Zeitpunkt zwei Untergruppen von Knoten gebildet, deren Aktivierungsniveaus jeweils in sich maximal kohärent sind, jedoch untereinander maximal unterschiedlich.

PCS-Modelle wurden bislang zur Untersuchung unterschiedlicher mentaler Prozesse verwendet. Während in den frühen Arbeiten der Ansatz zur Beschreibung basaler Wahrnehmungsfunktionen zum Beispiel von Buchstaben und Wörtern eingesetzt wurde (McClelland & Rumelhart, 1981), erstreckt sich das Anwendungsspektrum mittlerweile auch auf eine Vielzahl höherer und komplexerer mentaler Prozesse. PCS-Netzwerke haben dabei einen wesentlichen Beitrag zur kognitionspsychologischen Theorienbildung in unterschiedlichen Bereichen wie beispielsweise in der sozialen Wahrnehmung (Read & Miller, 1998), in der Verwendung von Analogien (Holyoak & Thagard, 1989), im schlussfolgernden Denken und Entscheiden (P. Thagard & Millgram, 1995), in der Eindrucksbildung (Kunda & Thagard, 1996), in der Bewertung von Erklärungsansätzen (Thagard, 1989), im probabilistischen Schließen (Glöckner & Betsch, 2008) oder im moralischen Urteilen (Holyoak & Powell, 2016) geleistet. Die mittels der PCS-Ansätze modellierten Kohärenzeffekte konnten auch in experimentellen Untersuchungen beispielsweise bei Einstellungsänderungen (Spellman, Ullman, & Holyoak, 1993), Präferenzentscheidungen (Simon et al., 2008; Simon, Krawczyk, & Holyoak, 2004) oder sozialem und moralischem Urteilen (Lee & Holyoak, 2020; Dan Simon, Stenstrom, & Read, 2015) nachgewiesen werden.

In einer Reihe theoretischer Arbeiten wurden die verschiedenen existierenden Modelle zu einer einheitlichen Kohärenztheorie weiterentwickelt und damit wurde die Allgemeingültigkeit der Kohärenzmechanismen für kognitive Prozesse der Entscheidungsbildung verdeutlicht (vgl. Read & Miller, 1998; Paul Thagard, 2000). Auch in der Einstellungsforschung existieren erste Versuche, ein auf dem PCS-Mechanismus basierendes allgemeines Modell der Einstellungsbildung und -änderung zu konzipieren (vgl. Monroe und Read 2008). Der PCS-Mechanismus im Kontext von Einstellungen besagt, dass einzelne auf ein Einstellungsobjekt bezogene Überzeugungen wechselseitige Beschränkungen aufeinander ausüben. Wenn beispielsweise eine Überzeugung gegenüber einem Einstellungsobjekt (z. B. Fahrradfahren ist umweltfreundlich) aktiviert wird, werden auch alle anderen mit diesem Objekt positiv assoziierten Überzeugungen aktiviert (z. B. Fahrradfahren ist gesund, kostengünstig, flexibel) und negativ verknüpfte Überzeugungen werden unterdrückt (z. B. Fahrradfahren ist langsam und unkomfortabel). Auf diese Weise werden die unterschiedlichen gegebenenfalls widersprüchlichen Einstellungsaspekte ausbalanciert und konsistente weitestgehend widerspruchsfreie Repräsentationen des Einstellungsobjekts geschaffen. Mittels Simulationsstudien konnten Monroe &

Read (2008) zeigen, dass das von den Forschern entwickelte konnektionistische Modell (*Attitudes as Constraint Satisfaction*, ACS) eine Reihe zentraler Eigenschaften und empirischer Befunde der Einstellungsforschung wie zum Beispiel motivierte Kognition, Einstellungspolarisierung, zentrale vs. periphere Überredung reproduzieren und erklären kann. Des Weiteren verfügt das ACS-Modell über eine wichtige in vorherigen Modellen nicht vorhandene dynamische Komponente, die durch die Modifizierbarkeit der Verbindungsgewichte im PCS-Netzwerk die Modellierung von Lernprozessen ermöglicht.

Eine wesentliche Einschränkung der oben dargestellten PCS-Ansätze ist deren Fokus auf kognitiv-rationale Aspekte von Einstellungen und Entscheidungen. Umfangreiche Forschungsarbeiten von der Philosophie bis zu den Neurowissenschaften zeigen jedoch, dass Emotionen und Affekte einen starken und manchmal nicht vorhersehbaren Einfluss auf die Entscheidungsfindung und Urteilsbildung von Menschen haben (für einen Überblick siehe Lerner et al., 2015). In den letzten Jahren wurden in Folge verschiedene Ansätze vorgeschlagen, die bestehende PCS-Modelle um eine affektiv-emotionale Komponente erweitert haben (z. B. Nerb, 2007; Sander, Grandjean, & Scherer, 2005; Schröder & Thagard, 2013; Dan Simon et al., 2015). Die von Paul Thagard vorgeschlagene Theorie der *emotionalen Kohärenz* (*emotional coherence)* stellt den ersten allgemeinen theoretischen Ansatz dar*,* der neben den „kalten Kognitionen", wie Interpretationen von Fakten oder analogen Schlussfolgerungen, auch sogenannte „heiße Kognitionen", wie Emotionen oder Gefühle, in einem konnektionistischen Modell HOTCO (Abkürzung für „HOT COherence") integriert (Thagard, 2003, 2006). Die Theorie versucht, damit zu erklären, wie die von Individuen getroffenen Entscheidungen oder Schlussfolgerungen durch das Zusammenspiel von Kognitionen und Gefühlen gegenüber Menschen, bestimmten Sachverhalten oder Situationen beeinflusst werden. Gemäß diesem Ansatz haben mentale Repräsentationen, wie Überzeugungen oder Fakten, zusätzlich zu ihrem kognitiven Charakter auch noch einen emotionalen Aspekt der Valenz. Diese kann entweder positiv oder negativ sein, je nach Gefühl dieser Repräsentation. Emotional coherence wurde auf Basis des PCS-Modells ECHO (Abkürzung für „Explanatory Coherence") formalisiert (siehe Thagard, 1989). Durch die Ergänzung eines zusätzlichen Valenzknotens in dem PCS-Netzwerk beeinflussen emotionale Reaktionen kognitive Schlussfolgerungen und umgekehrt. Mit dem Modell konnte ein relativ weites Spektrum individueller psychologischer Phänomene sowie sozial beeinflusster Verhaltensweisen erklärt werden (vgl. Paul Thagard, 2006).

Zusammenfassend ist festzuhalten, dass die Entwicklung konnektionistischer Modelle es ermöglicht hat, die in den Konsistenztheorien formulierten Prinzipien der Informationsverarbeitung mathematisch präzise und allgemeingültig zu formulieren. Auf Basis des zentralen Mechanismus der Konsistenz- beziehungsweise Kohärenzmaximierung konnte somit eine Vielzahl bekannter

Entscheidungs- und Einstellungsphänomene beschrieben und erklärt werden. Die von Paul Thagard vorgeschlagene und formalisierte Theorie der emotionalen Kohärenz stellt eine wichtige Weiterentwicklung dar, um die Effekte der Wechselwirkung von Kognitionen und Gefühlen im Zuge von Entscheidungsprozessen psychologisch plausibel abzubilden und zu erklären. Zudem können mit dem Modell HOTCO unterschiedliche Formen der sozialen Kommunikation und des Informationsaustauschs (z. B. rational vs. emotional) repräsentiert und berücksichtigt werden (z. B. Thagard & Kroon, 2006). Dieses PCS-Modell dient als theoretische Grundlage für die weiter unten dargestellte Konzeption und Entwicklung des Multiagentenmodells und für die in diesem Zusammenhang durchgeführten empirischen Arbeiten. Für die realistische Simulation sozialer Dynamiken zu Mobilitätsinnovationen werden sowohl theoretische und technische Modifikationen als auch empirisch-experimentelle Überprüfungen des Modells durchgeführt. Diese umfassen folgende Aspekte: 1) Erweiterung von HOTCO um einen Lenkmechanismus, 2) empirische Fundierung der für Verkehrsmittelentscheidungen relevanten Handlungsmotive, 3) experimentelle Untersuchung der Modifikation von Überzeugungen und Gefühlen durch persuasive Kommunikation sowie 4) die umfassende empirisch basierte Parametrisierung der wichtigsten Modellparameter.

2.2 Sozialer Einfluss

Menschen sind ihrem Alltag vielfältigen sozialen Einflüssen ausgesetzt. Individuelle Einstellungen und Verhaltensweisen werden beiläufig oder absichtlich durch das soziale Umfeld beeinflusst und verändert. In der Sozialpsychologie spricht man in diesem Zusammenhang von Veränderungen infolge normativen oder informationalen *sozialen Einflusses* (vgl. Deutsch & Gerard, 1955). Bei dem erstgenannten Mechanismus handelt es sich um Regeln und Standards, die innerhalb einer Gruppe geteilt werden und menschliches Verhalten oft implizit lenken (Cialdini & Trost, 1998). Informationaler Einfluss hingegen beruht auf Informationen wie persuasiven Argumenten, Wissen oder Meinungen, die Personen beispielsweise im Zuge von Diskussionen austauschen. Die Erforschung der Mechanismen und Effekte sozialen Einflusses zählt zu den zentralen Forschungsfeldern der Sozialpsychologie, die insbesondere auf Gruppenebene umfassende und vielfältige theoretische wie auch empirische Ergebnisse hervorgebracht hat. Auf dieser Basis werden seit Mitte des 20. Jahrhunderts in diesem Forschungsbereich auch formale, agentenbasierte Modelle und Simulationen entwickelt und eingesetzt (vgl. Gilbert, 2010; Gilbert & Troitzsch, 1999). Der Fokus dieser Arbeiten liegt größtenteils auf der Untersuchung informationalen sozialen Einflusses sowie den daraus entstehenden sozialen Dynamiken in großen Gruppen bis zu Gesellschaften. Eine der zentralen Fragestellungen, die mit einer Vielzahl unterschiedlicher Modellansätze untersucht worden ist, lautet: Wie entsteht gesellschaftliche Diversität von Werten, Meinungen und Einstellungen und warum bleibt sie im zeitlichen Verlauf erhalten (z. B. Abelson, 1964; Axelrod, 1997; Hegselmann & Krause, 2002; Macy, Kitts, Flache, & Benard, 2003; Mäs, Flache, & Helbing, 2010)?

Von diesen sogenannten Einstellungs- und Meinungsmodellen (eng. *opinion dynamics models*) sind Modellierungsansätze abzugrenzen, die sich mit den Bedingungen der Diffusion von Informationen, Innovationen oder Verhalten in sozialen Systemen beschäftigen (vgl. Valente, 1995). Der zentrale Unterschied zwischen Diffusionsmodellen und Modellen von Einstellungs- und Meinungsdynamiken ist, dass erstgenannte Modelle in der Regel von uni- und letztere von bidirektionaler Wirkung sozialer Einflüsse ausgehen. Obgleich einige Innovationsdiffusionsmodelle auch Aspekte interpersonaler Kommunikation und Einstellungsbildung beinhalten, handelt es sich hierbei um eine andere Modellgruppe, die auf Basis anderer theoretischer Grundlagen und Annahmen zum Teil umfassendere Aspekte von menschlichem Verhalten und dessen Veränderungen modelliert (zur Übersicht siehe Kiesling, Günther, Stummer, & Wakolbinger, 2011; Negahban & Yilmaz, 2014).

In einem aktuellen Überblicksartikel fassen die Autoren Flache et al. (2017) bestehende agentenbasierte Modelle sozialen Einflusses vor dem Hintergrund ihrer jeweiligen theoretischen Prämissen in drei Kategorien zusammen: (a) Modelle sozialer Assimilation, (b) Modelle sozialer Ähnlichkeit und (c) Modelle mit sozialer Repulsion.

Die forschungsleitende Grundannahme von Modellen *sozialer Assimilation* lautet, dass sich zwei miteinander in Verbindung stehende Akteure derart beeinflussen, dass sich deren Meinungs- oder Einstellungsunterschiede reduzieren und sich somit ihre Positionen annähern. Nachdem individuelle Agenten in einer komplexeren sozialen Struktur eingebunden sind, ist es jedoch möglich, dass sich die Meinungen unterschiedlicher Gesprächspartner gegenseitig ausmitteln oder der Einfluss eines Agenten durch den eines einflussreicheren Agenten verdrängt wird. Modelle sozialer Assimilation wurden auf Basis unterschiedlicher theoretischer und empirischer Forschungsarbeiten zu den Effekten persuasiver Kommunikation (z. B. Myers, 1982), zu Imitation und sozialem Lernen in Peergruppen (z. B. Akers, Krohn, Lanza-Kaduce, & Radosevich, 1979), zu Konformität mit Gruppennormen (Allport, 1924; Asch, 1952) und zu kognitiver Dissonanzreduktion (Festinger, 1957; Heider, 1946) entwickelt. Zu den prominenten Beispielen dieser Modellgattung gehören unter anderem die Ansätze von Abelson (1964), Degroot (1974) und Lehrer (1975). Die Arbeiten konnten zeigen, dass in Populationen, in denen alle Agenten direkt oder indirekt miteinander verbunden sind, nach einer gewissen Zeit allgemeiner Konsens entsteht, wenn die Meinungen als kontinuierliche Variablen und nicht als nominale Variablen mit diskreten Entscheidungsoptionen repräsentiert werden. Damit stehen die Modellvorhersagen in deutlichem Widerspruch zu den Ergebnissen empirischer Forschung

(z. B. DellaPosta, Shi, & Macy, 2015; Liu & Srivastava, 2015) und liefern keine Erklärung für das Phänomen zunehmender Polarisierung in Gesellschaften.

Modelle der Kategorie *soziale Ähnlichkeit* rücken von der Annahme immerwährenden Einflusses vernetzter Akteure ab. Vielmehr hängt die Frage, ob und in welchem Ausmaß sozialer Einfluss wirksam ist, von der Ähnlichkeit der interagierenden Akteure ab. Die zentrale Annahme derartiger Modelle lautet, dass Agenten, deren Meinungen oder Einstellungen zu stark divergieren, aufeinander keinen Einfluss haben. Der Grad der Toleranz beziehungsweise die Schwelle nicht tolerierbarer Meinungsunterschiede sind neben dem Ausmaß der Anfangspolarisierung die entscheidenden Parameter dieser Modellkategorie. Die theoretischen und empirischen Grundlagen der Modelle sozialer Ähnlichkeit gehen auf zwei verschiedene Forschungsrichtungen zurück. Ein Teil der Arbeiten bezieht sich auf Erkenntnisse aus dem Bereich der Kognitions- und sozialpsychologischen Forschung. Diese betonen die Relevanz der Einstellungs- und Meinungsähnlichkeit zwischen Sender und Empfänger, um Einstellungsmodifikationen hervorrufen zu können (soziale Urteilstheorie, Sherif & Hovland, (1961); Bestätigungsfehler, Nickerson, (1998)). Der andere Teil der Modelle knüpft an soziologische Erklärungsansätze an, die im Besonderen die sozial-strukturelle Ähnlichkeit zwischen Personen als Voraussetzung für soziale Beeinflussung betonen. Diese beziehen sich entweder auf die Theorie des symbolischen Interaktionismus (Stryker, 1980), die postuliert, dass Informationssuche vornehmlich unter Personengruppen mit geteilten symbolischen Bedeutungen stattfindet, oder auf das Homophilie-Prinzip (McPherson, Smith-Lovin, & Cook, 2001), dem zufolge Menschen mit ähnlichen soziodemografischen Merkmalen mit einer höheren Wahrscheinlichkeit miteinander interagieren.

Die Forschung zu agentenbasierten Modellen *sozialer Ähnlichkeit* ist sehr umfangreich und stellt unter dem englischen Begriff *bounded confinence models* eine eigene Modellklasse dar (für einen Überblick siehe Castellano, Fortunato, & Loreto, 2009; Lorenz, 2007). Zu den einflussreichsten Arbeiten zählen die Modellansätze von Deffuant, Neau, Amblard, & Weisbuch (2000) und Hegselmann & Krause (2002). Modelle dieser Kategorie liefern eine Erklärung, wie Diversität unter sozialem Einfluss erhalten bleiben kann. Dennoch entstehen Meinungscluster beziehungsweise -diversität nur dann, wenn die Streuung der Meinungen zu Beginn der Simulation hinreichend groß ist. Die Ursache für die Entstehung von Diversität kann durch Modelle sozialer Ähnlichkeit nicht veranschaulicht werden. Ferner ist die Annahme, dass Akteure mit zu unterschiedlichen Meinungen in der realen Welt nicht in Kontakt kommen, unplausibel und unrealistisch.

Zur dritten Modellkategorie sogenannter *repulsiver Einflüsse* gehören Modelle, die Effekte der Assimilationen mit denen der Differenzierung von Meinungen und Einstellungen kombinieren. In der

Literatur wird der Mechanismus repulsiven sozialen Einflusses auch negativer Einfluss, Reaktanz, Zurückweisung, Differenzierung oder Bumerangeffekt genannt. Die Grundannahme, dass sich bestehende Unterschiede von Meinungen und Einstellungen durch sozialen Einfluss verstärken, beruht auf den zwei Prämissen. Erstens, dass Menschen negativ bewertet werden, wenn sie sich hinsichtlich salienter Merkmale von der beurteilenden Person (Beobachter, Empfänger, Zuhörer) unterscheiden (Byrne, Core, & Smeaton, 1986; Chen & Kenrick, 2002; Rosenbaum, 1986). Zweitens, dass sich Unterschiede zu negativ bewerteten Personen durch die Anpassung von Meinungen und Einstellungen verstärken (Festinger, 1957; Heider, 1946). Modelle repulsiven Einflusses wurden ebenso wie Modellansätze sozialer Assimilation und sozialer Ähnlichkeit sowohl für kontinuierliche als auch diskrete Meinungsrepräsentationen umgesetzt. Der Mechanismus kann in die oben beschriebenen Modellkategorien (a) und (b) integriert werden. In diesem Zusammenhang wurden unterschiedliche Prinzipien entwickelt: Jager und Amblard (2005) schlugen ein Schwellenwertmodell vor, in dem sie je nach Grad des Meinungsunterschieds zwischen den Akteuren entweder Assimilation (bei geringen Abweichungen), Differenzierung (bei großen Abweichungen) oder keine Veränderung annehmen. In den Meinungsmodellen von Feliciani, Flache, & Tolsma (2017); Flache und Mäs (2008) oder Macy et al. (2003) wurden zur Gewichtung der Ähnlichkeit neben der Meinung auch noch demografische Dimensionen einbezogen. In einer anderen Modellvariante repulsiver Meinungsänderung wird die Gewichtung auf Basis der Ähnlichkeit unter den Akteuren berechnet. Galam (2004) führt dazu Nonkonformisten ein, die, sobald sich eine lokale Mehrheitsmeinung unter den anderen Agenten gebildet hat, von dieser abweichen. Grundsätzlich können Modelle repulsiven Einflusses die Entstehung von sozialer Diversität erklären und sind robust gegenüber zufälligen Veränderungen. Unter welchen Bedingungen allgemeiner Konsens, bipolare oder multipolare Meinungscluster entstehen, hängt jedoch von diversen Bedingungen ab, wie zum Beispiel der Meinungsvarianz zu Simulationsbeginn, der Anzahl der Meinungsdimensionen, der Netzwerkstruktur sowie von der Frage, ob sich Agenten von anderen mit ähnlicher oder unähnlicher Meinung unterscheiden wollen.

Neben den verschiedenen Mechanismen sozialen Einflusses auf der Mikroebene spielen für die Entwicklung von Meinungsdynamiken die Strukturen *sozialer Netzwerke* auf der Mesoebene, innerhalb derer Personen Informationen austauschen, eine wesentliche Rolle (Guilbeault, Becker, & Centola, 2018). Dabei sind strukturelle Merkmale wie Grad der Vernetzung, Dichte des Netzwerks und Clusterung der Akteure die wesentlichen Einflussfaktoren, deren Effekte mithilfe agentenbasierter Modellierung in dynamischen Systemen untersucht werden können (Lorenz, 2007; Macy & Willer, 2002; Montanari & Saberi, 2010). Aufgrund fehlender empirischer Daten von realen sozialen Netzwerken werden hierzu häufig theoretische oder auch zufallsbasierte Netzwerkansätze zur Modellierung sozialer Strukturen verwendet (z. B. Amblard, 2002; Amblard & Deffuant, 2004; Deffuant et al., 2000; Moussaïd, 2013). In jüngeren Arbeiten wurden in diesem Zusammenhang auch personenbezogene Merkmale und Daten aus Fragebogenstudien (z. B. Alter, Wohnort etc.) mit theoretischen Konzepten der Netzwerkforschung kombiniert, um somit realistischere Netzwerke zu generieren (z. B. DellaPosta et al., 2015; Robinson & Rai, 2015). In diesem Zusammenhang ist das *Prinzip der Homophilie*, die Tendenz von Menschen, sich mit anderen Personen mit ähnlichen Merkmalen und Meinungen zu vernetzen, einer der am häufigsten verwendeten Mechanismen (Burt, 1991; Marsden, 1988; McPherson et al., 2001; McPherson, Miller, & Smith-Lovin, 1987). Theoretisch wird dabei zwischen zwei verschiedenen Formen unterschieden, durch die Homophilie entsteht – der *Wahlhomophilie* (*choice homophily*) und der *induzierten Homophilie (induced homophily)* (McPherson et al., 1987). Von Wahlhomophilie spricht man, wenn sich Beziehungen auf individuelle psychologische Präferenzen zurückführen lassen. Sobald Verbindungen nachweislich als Folge struktureller Interaktionsmöglichkeiten entstehen, zum Beispiel in Nachbarschaften, an Arbeitsplätzen, in Ausbildungseinrichtungen oder in Freundeskreisen, spricht man von induzierter Homophilie. In den oben dargestellten modellbasierten Forschungsarbeiten zu sozialem Einfluss überwiegen jedoch rein theoretische Ansätze, die nur selten empirisch validiert wurden (vgl. Andreas Flache et al., 2017).

Zusammenfassend kann also festgehalten werden, dass die hier dargestellten Modellkategorien – wenn auch nicht vollständig – die zentralen theoretischen Modellvarianten sozialen Einflusses umfassen. Obgleich die erwähnten Arbeiten zum besseren theoretischen Verständnis komplexer Dynamiken sozialen Einflusses beitragen haben, bestehen dennoch weiterhin diverse Einschränkungen und Forschungslücken, um in diesem Kontext für reale soziale Phänomene Erklärungen oder Vorhersagen liefern zu können. Bei den Ansätzen handelt es sich in der Regel um sehr abstrakte Repräsentationen sozialer Systeme ohne detaillierte empirische Grundlagen und mit stark vereinfachten Annahmen hinsichtlich der kognitiven Mechanismen menschlicher Informationsverarbeitung und Entscheidungsfindung sowie der Entstehung und Veränderung sozialer Netzwerke. Die verwendeten Konstrukte wie Meinungen, Einstellungen oder Werte werden häufig nur unzureichend differenziert und ohne Bezug zur aktuellen sozial- und kognitionspsychologischen Forschung definiert. Zudem werden die für Entscheidungsprozesse und soziale Interaktionen bedeutsamen Aspekte wie zum Beispiel die Wirkung von Affekten und Emotionen nicht hinreichend berücksichtigt. Die vorliegende Dissertation versucht, diese Forschungslücken zu schließen, indem sie bei der Modellbildung sowohl auf der Mikro- als auch Mesoebene auf aktuelle theoretische Konzepte und empirische Erkenntnisse der Kognitions- und Sozialpsychologie zurückgreift. Zudem werden zur Validierung der zentralen Modellannahmen eigene empirisch-experimentelle Untersuchungen durchgeführt.

2.3 Typenbildung und Segmentierung

In den Bereichen der Umwelt- und Verkehrspolitik werden üblicherweise ordnungsrechtliche, fiskalpolitische und marktwirtschaftliche Instrumente zur Veränderung von Verhaltensmustern eingesetzt. Die Wirksamkeit und Realisierbarkeit der Maßnahmen hängt jedoch auch von der gesellschaftlichen Akzeptanz der Interventionen ab, die durch transparente Kommunikation, Beteiligung und den Einsatz von (persuasiven) Informationskampagnen verstärkt werden kann (Stroebe & Hewstone, 2014). Sozialwissenschaftliche *Typenbildungen* oder *Zielgruppensegmentierungen* haben sich dabei zum Zweck der effektiven Gestaltung von Kommunikationsmaßnahmen als nützlich erwiesen (de Haan, Lantermann, Linneweber, & Reusswig, 2001; Hine et al., 2014). Das Einsatzgebiet der sowohl qualitativ als auch quantitativ umsetzbaren Verfahren ist vielfältig und reicht vom Gesundheitsbereich (Mathijssen, Janssen, van Bon-Martens, & van de Goor, 2012) über die Wählermobilisierung (Bland, 2013) bis hin zu verschiedenen Handlungsfeldern im Kontext des Klimawandels (Maibach, Leiserowitz, Roser-Renouf, & Mertz, 2011; Poortinga & Darnton, 2016).

Die Zielgruppensegmentierung zählt zu den zentralen Methoden des sogenannten *sozialen Marketings* – ein Verfahren, das Konzepte und Techniken aus dem kommerziellen Marketing nutzt, um die Umsetzung umfassender gesellschaftlicher Ziele (z. B. Verkehrs- oder Energiewende) zu unterstützen und zu fördern (Alan, 2006; Kotler & Zaltman, 1971). Ziel dieses Vorgehens ist es, mithilfe empirischer Verfahren die jeweiligen Bedürfnisse, Überzeugungen und Verhaltensweisen unterschiedlicher Zielgruppen zu identifizieren, um somit Interventionen zielgruppenspezifisch darauf anpassen und ausrichten zu können. Die Aggregation individueller Merkmalsausprägungen auf Gruppenebene ist logischerweise mit einem Informationsverlust verbunden, der sich sowohl hinsichtlich des allgemeinen Erklärungs- als auch des praktischen Werts negativ beziehungsweise kontraproduktiv auswirken kann (Corner & Randall, 2011). Dennoch sprechen methodisch-theoretische und praktische Aspekte für den Einsatz von Zielgruppenansätzen im Kontext persuasiver Kommunikation (vgl. Hunecke, 2015). So sind statistische Verfahren wie zum Beispiel Regressions- und Strukturgleichungsmodelle hinsichtlich der Identifikation von Merkmalszusammenhängen, die nur in bestimmten Subgruppen des Samples auftreten, nicht hinreichend sensitiv. Dies kann zur Unterschätzung oder Nichtberücksichtigung relevanter Wirkbeziehungen in bestimmten Teilgruppen führen. Die Charakterisierung und Bestimmung spezifischer Merkmalsausprägungen kann hier einerseits Erklärungsmodelle für bestimmte Subgruppen verbessern und andererseits Ansatzpunkte für wirksame Interventionen liefern. Weiterhin wird durch die Entwicklung von Zielgruppenansätzen der Transfer von abstrakten wissenschaftlichen Erkenntnissen und die Ableitung von Handlungsempfehlungen insbesondere im Rahmen von anwendungsorientierter und transdisziplinärer Forschung verbessert.

Im Mobilitätsbereich existiert mittlerweile eine Vielzahl von quantitativ gebildeten Typologien, die in vier Kategorien unterteilt werden können: geografische (z. B. BMVBS, 2012), verhaltensbezogene (z. B. Prillwitz & Barr, 2011), soziodemografische (z. B. Hildebrand, 2003) und psychografische (z. B. M. Hunecke, Haustein, Bohler, & Grischkat, 2008) Verfahren. Zur Bewertung der Nützlichkeit von Segmentierungsansätzen wurden unterschiedliche Kriterien wie Verhaltensrelevanz, Messgenauigkeit, zeitliche Stabilität vorgeschlagen (vgl. Dibb, 1999). Der systematische Vergleich der vier Verfahren der Typenbildung zeigt, dass trotz spezifischer Vor- und Nachteile der einzelnen Methoden einstellungsbasierte (psychografische) Segmentierungsansätze für die Vorhersage der Verkehrsmittelwahl und die Entwicklung zielgruppenspezifischer Informationskampagnen am besten geeignet sind (vgl. Hunecke, 2015).

Der Großteil psychografischer Typologien umfasst verschiedene Einstellungsdimensionen und instrumentelle Handlungsmotive gegenüber konventionellen Verkehrsmitteln und wurde zur Förderung umweltfreundlicher Verkehrsmittelnutzung entwickelt (z. B. Anable & Gatersleben, 2005; M. Hunecke et al., 2008; Li, Z., Yang, Wang, & Ragland, 2013; Prillwitz & Barr, 2011; Pronello & Camusso, 2011; Shiftan, Outwater, & Zhou, 2008). Aktuelle Segmentierungsstudien haben zudem einzelne neuere Mobilitätsformen wie E-Fahrzeuge oder Carsharing in die Profilbildung der Segmente aufgenommen, um auf dieser Basis Strategien für den Umstieg auf diese relativ neuen Fortbewegungsformen abzuleiten (z. B. Kandt, Rode, Hoffmann, Graff, & Smith, 2015). Vor dem Hintergrund der Erkenntnisse über die Relevanz *symbolisch-affektiver* Bedeutungen für Mobilitätsentscheidungen (z. B. Axsen & Kurani, 2011a; Schuitema, Anable, Skippon, & Kinnear, 2013) wurden in jüngeren Zielgruppenansätzen neben kognitiven Faktoren auch affektive und symbolische Bedeutungen neuer Mobilitätsformen integriert (z. B. Anable, Kinnear, Hutchins, & Skippon, 2016; Morton, Anable, & Nelson, 2017). Aufgrund der inkonsistenten Operationalisierung symbolisch-affektiver Merkmale werden jedoch in den einzelnen Studien unterschiedliche Aspekte dieser Konzepte erfasst beziehungsweise mit anderen psychologischen Konstrukten (z. B. Emotionen) konfundiert. Zudem erfolgt die Auswahl typenkonstituierender Variablen, abgesehen von einigen wenigen Ausnahmen (z. B. Jillian Anable, 2005; Bösehans & Walker, 2018; M. Hunecke et al., 2010), ohne kohärente theoretische Basis, sodass die Ergebnisse vielfach keine Generalisierung erlauben.

Mit der *Affektsteuerungstheorie* (*Affect control theory*) liegt eine umfassende Handlungstheorie vor, die die Verbindung zwischen emotionalem Erleben sowie sozialen und kulturellen Strukturen betont (Heise, 2007; 2010). Die Kernthese der Theorie ist, dass Menschen bei der Interpretation einer Situation beziehungsweise Wahl ihrer Handlungen und Entscheidungen vornehmlich von deren jeweiligen affektiven Bedeutungen geleitet werden (MacKinnon, 1994). Die affektive Bedeutung von sprachlichen Begriffen und Konzepten kann durch die drei universalen Basisdimensionen *Evaluation,* *Potenz und Aktivation* charakterisiert werden (vgl. Fontaine, Scherer, Roesch, & Ellsworth, 2007; Osgood, Suci, & Tannenbaum, 1957). Diese empirisch erhobenen Bewertungen von Wortbedeutungen spiegeln affektive Reaktionen gegenüber Objekten, Identitäten oder Handlungen wider, die innerhalb einer Kultur beziehungsweise Subgruppen einer Gesellschaft geteilt werden (Heise, 2010; Neil J. MacKinnon & Heise, 2010). Der dreidimensionale Affektraum entspricht den grundlegenden Dimensionen menschlicher Wahrnehmung, Emotionen, (nonverbaler) Kommunikation sowie sozialer Interaktion (Scholl, 2013). Die Repräsentationen sind innerhalb von Kulturen über lange Zeiträume stabil (Heise, 2010), können sich jedoch auch zwischen unterschiedlichen sozialen Gruppen innerhalb einer Gesellschaft deutlich unterscheiden (z. B. Ambrasat, von Scheve, Conrad, Schauenburg, & Schröder, 2014). Affektive Steuerungsmechanismen erlauben Individuen, rasch und effektiv auf Veränderungen in der Umwelt zu reagieren. Darüber hinaus haben sie sowohl im Zuge sozialen Handelns wie auch im Bereich Konsum eine identitätsstiftende und handlungsleitende Funktion (Heise, 2007; Shank & Lulham, 2016b, 2016a). Erste Arbeiten im Bereich der Parteiidentifikation konnten zeigen, dass affektive Bedeutungen von Parteien als sparsame und effektive Indikatoren zur Typenbildung geeignet sind und intendiertes Wahlverhalten vorhersagen können (Ambrasat, 2017).

Zusammenfassend lässt sich feststellen, dass die sozialwissenschaftliche Typen- beziehungsweise Zielgruppenbildung besonders in handlungsorientierten Forschungsfeldern immer häufiger zur Anwendung kommt. Im Mobilitätsbereich existiert mittlerweile eine Vielzahl unterschiedlicher Verfahren zur Zielgruppendefinition. Zur Entwicklung einer zielgruppengerechten Intervention haben sich dabei psychografische Typologien am effektivsten erwiesen. Es fehlen jedoch konsistente theoretisch begründete psychografische Typologien, die die für das Innovationsgeschehen besonders relevanten Aspekte der affektiven Bedeutungen und Reaktionen der infrage kommenden Handlungsoptionen umfassen. Weiterhin liegen bislang vielfach keine Belege für die Wirksamkeit der in einigen Segmentierungsstudien vorgeschlagenen Interventions- und Kommunikationsmaßnahmen zur Veränderung von Mobilitätsverhalten vor. Ausgehend von den theoretischen Annahmen und vom methodischen Vorgehen der Affektsteuerungstheorie wird in dieser Dissertation ein neuerer Segmentierungsansatz für nachhaltige Mobilitätsformen vorgeschlagen und validiert. Durch die Integration des Ansatzes in das Simulationsmodell *InnoMind* können die Effekte von Politik- und Kommunikationsmaßnahmen auf unterschiedliche Zielgruppen untersucht werden.

3 Forschungsfragen

Die allgemeine Zielsetzung der Dissertation besteht darin, das Verständnis sozialer Dynamiken im Zuge gesellschaftlicher Transformationen im Bereich Mobilität zu verbessern. Zu diesem Zweck wird auf Basis empirisch-experimenteller Arbeiten ein neues agentenbasiertes Modell (*InnoMind*) entwickelt, das drei zentrale Schwächen bestehender Simulationsansätze zur Einstellungsbildung und zur sozialen Beeinflussung adressiert: Erstens sind in bisherigen Modellen zentrale Parameter und Annahmen nur unzureichend empirisch begründet beziehungsweise experimentell überprüft. Zweitens werden in bestehenden Ansätzen intrapsychische, insbesondere affektiv-emotionale Prozesse der Informationsverarbeitung und die damit verbundenen Verzerrungseffekte nicht ausreichend berücksichtigt. Drittens lassen bisherige Modelle mehrheitlich die Rolle affektiv-emotionaler Faktoren zwischenmenschlicher Kommunikation außer Acht.

Vor dem Hintergrund des bisherigen Forschungsstands in den für die Forschungsarbeit relevanten Themenfeldern (siehe Kap. 2) wurden drei zentrale Forschungsfragen formuliert, die unterteilt in mehrere Unterfragen in vier einzelnen Teilstudien bearbeitet wurden. Die Untergliederung folgt der analytischen Trennung auf Mikro- (individuelle und dyadische), Meso- (Teilgruppen-) und Makroebene (Aggregat- oder Gesamtpopulation).

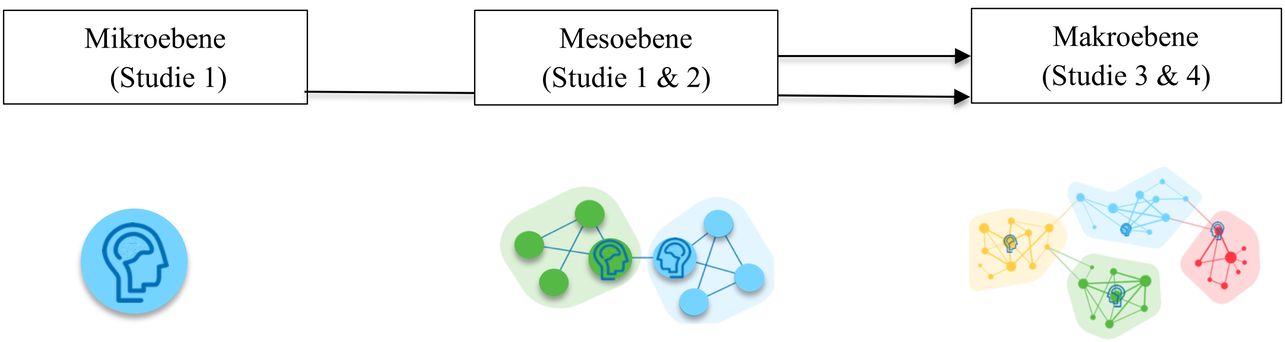

Abbildung 1: Mehrebenenmodell und Studienübersicht

Mikroebene – 1. Forschungsfrage: Welchen Einfluss hat die Verwendung emotionaler Sprache im Kontext persuasiver Kommunikation auf die Informationsverarbeitung von Menschen?

Studie (Wolf, I. & Schröder, T., in Begutachtung): Vignettenexperiment zur Untersuchung der Wirkung (emotionaler) persuasiver Kommunikation auf Einstellungen gegenüber konventionellen und neueren Mobilitätsformen. Folgende Unterfragen wurden für die Studie formuliert:

a. Wird die Tendenz zu motivierter Informationsverarbeitung (motivierte Kognition) durch den emotionalen Gehalt persuasiver Kommunikation beeinflusst?
b. Können die experimentellen Ergebnisse mithilfe eines PCS-Modells dyadischer Kommunikation reproduziert und erklärt werden?
c. Welchen Effekt haben unterschiedliche Formen persuasiver Kommunikation auf die den Einstellungen zugrunde liegenden mentalen Strukturen?

Mesoebene – 2. Forschungsfrage: Welche Bedeutung haben affektive Wahrnehmungen von Verkehrsangeboten für die Akzeptanz und Bereitschaft zur Verhaltensveränderung im Mobilitätsbereich?

Studie (Wolf, I. & Schröder, T., 2019): Befragungsstudie zur Erfassung der Einstellungen und Nutzungsintentionen gegenüber konventionellen und neueren Mobilitätsformen. Folgende Unterfragen wurden für die Studie formuliert:

a. Welchen Einfluss haben die Kenntnisse, Einstellungen und Bewertungen der Bürgerinnen und Bürger in Deutschland gegenüber konventionellen und neueren Formen der Mobilität auf die Nutzungsbereitschaft der Verkehrsmittel?
b. Können auf Basis der affektiven Bewertungen von Verkehrsmitteln Zielgruppen definiert werden, die sich hinsichtlich ihres aktuellen und intendierten Verkehrsverhaltens unterscheiden?
c. Welche zielgruppenspezifischen Interventionen lassen sich auf Grundlage des entwickelten Ansatzes ableiten?

Makroebene – 3. Forschungsfrage: In welcher Weise können die psychologischen und sozialen Prozesse sowie politischen Einflüsse der Einstellungsbildung gegenüber Mobilitätsinnovationen in einem agentenbasierten Modell psychologisch plausibel und problemadäquat abgebildet werden?

Studie (Wolf, I., Schröder, T, Neumann, J., de Haan, G., 2015): Entwicklung eines agentenbasierten Modells und Simulation sozialer Einflüsse und politischer Maßnahmen auf Einstellungen gegenüber konventionellen und neuen Mobilitätsformen: Folgende Unterfragen wurden für die Studie formuliert:

a. Welche Modellstrukturen und Konzepte sind geeignet, um Einstellungsdynamiken im Mobilitätsbereich plausibel und realistisch zu modellieren?

b. In welcher Weise können die empirischen Ergebnisse in die Modellstruktur integriert werden?

c. Welche voraussichtlichen Einstellungsänderungen und Dynamiken ergeben sich aufgrund sozialer Einflüsse in der Bevölkerung?

d. Welche voraussichtliche Wirkung haben politische Maßnahmen zur Förderung von Elektromobilität in Berlin und welche Schlüsse lassen sich daraus für die Gestaltung und Implementierung von Interventionen ziehen?

Studie (Schröder, T. & Wolf, I., 2017): Anwendung des agentenbasierten Modells *InnoMind* zur Untersuchung der Wirkung von Carsharingkampagnen mit unterschiedlichem Framing der Informationen.

e. Welche Bedeutung haben bedürfnisorientierte Informationskampagnen über Carsharing auf die Nutzungspräferenzen des Verkehrsangebots?

4 Methodisches Vorgehen

In den folgenden Abschnitten wird das methodische Vorgehen der vier Studien skizziert, die Bestandteil dieser Dissertation sind. Dabei wird sich vor allem auf die Beschreibung der eingesetzten Verfahren konzentriert. Eine vollständige Darstellung der methodischen Details sind in den jeweiligen Methodenteilen der Forschungsartikel zu finden. Teile der Arbeiten wurden vom Verfasser der vorliegenden Dissertation im Zuge der BMBF finanzierten Drittmittelprojekte INNO-SIM (Studie 1 und 3) und MonForSense (Studie 2 und 4) konzipiert und durchgeführt.

Studie 1

Zur Untersuchung der Wirkung persuasiver Kommunikation auf Einstellungen gegenüber Verkehrsmitteln wurde die Methode des faktoriellen Surveys (auch Vignettenanalyse genannt) gewählt. Die Grundidee der Vignettenanalyse besteht darin, die Befragten hypothetische Personen-, Objekt- oder Situationsbeschreibungen – sogenannte „Vignetten" – beurteilen zu lassen. Die Vignetten bestehen aus einzelnen für die Fragestellung relevanten Elementen, sogenannten Merkmalen oder Dimensionen, deren Ausprägungen (Levels) systematisch variiert werden (Beck & Opp, 2001; Jasso, 2006). Ziel der anschließenden Analyse ist es, die Urteilsrelevanz der einzelnen Merkmale zu identifizieren und Unterschiede zwischen Personen oder Personengruppen zu erklären. Im Gegensatz zum Vorgehen bei klassischen Befragungen werden bei Vignettenanalysen Merkmale nicht einzeln abgefragt, sondern in situative Beschreibungen integriert.

In der ersten Studie der vorliegenden Dissertation ging es darum, die Erfahrungen und Empfehlungen einer fiktiven Person zur Nutzung bestimmter Verkehrsmittel zu bewerten. Zentrale Annahme dabei war, dass die Bewertungen von der Übereinstimmung der Einstellungen zwischen Sender (Aussagen der Vignette) und Empfänger (Teilnehmer*in) und dem Grad der Emotionalität der Aussagen beeinflusst werden. Dementsprechend wurden neben der Art der Argumentation (emotional vs. rational) Dimensionen ausgewählt, die besonders relevante Faktoren bei der Verkehrsmittelwahl darstellen. Als Grundlage hierfür dienten die im Rahmen des Forschungsprojekts INNO-SIM durchgeführten Fokusgruppenanalysen und eine Fragebogenstudie (vgl. Wolf & de Haan, 2013). In Tabelle 1 sind die Dimensionen und Ausprägungen der Vignetten dargestellt.

Tabelle 1: Dimensionen und Ausprägungen der Vignetten

Dimensionen	**Ausprägungen**
Argumentation	rational/emotional/kombiniert (rational-emotional)
Verkehrsmittel	konventionelles Auto/Elektroauto
Valenz	positiv/negativ
Mobilitätsbedürfnis	Komfort/Unabhängigkeit/Umweltfreundlichkeit/Fahrerlebnis/gutes Gewissen; jeweils zwei pro Vignette

Zur Erstellung des Vignettenuniversums (Summe aller möglichen Kombinationsmöglichkeiten von Dimensionen und Ausprägungen) wurden alle Merkmalsausprägungen miteinander gekreuzt. In jeder Vignette wurden jeweils zwei Ausprägungen der Dimension *Mobilitätsbedürfnis* aufgenommen. Damit ergeben sich für die drei Ausprägungen der Dimension *Argumentation* jeweils 40, insgesamt 120 unterschiedliche Vignetten. Aufgrund der hohen Gesamtzahl wurden pro Argumentationsform jeweils 4 Vignettensets mit jeweils 10 Vignetten erstellt. Alle Vignetten wurden im Rahmen einer Vorstudie auf Verständlichkeit und emotionale Salienz getestet. Die Programmierung des Online-Experiments wurde mit der Software Unipark realisiert. Die Teilnehmerrekrutierung und die Datenerhebung wurden durch das Marktforschungsunternehmen Respondi AG vorgenommen.

In der Hauptstudie wurden die n = 480 Teilnehmer:innen zufällig einer der drei Formen persuasiver Kommunikation (Ausprägung: rational/emotional/kombiniert (rational-emotional)) und einem entsprechenden Vignettenset zugewiesen. Die Bewertung der Vignetten erfolgte auf fünf Antwortskalen, auf denen die Befragten bewerteten, a) inwieweit sie die Aussagen teilen können (6-stufig), b) inwiefern die Aussage ihre Meinung gegenüber dem Verkehrsmittel geändert hat (7-stufig), c) wie sympathisch (6-stufig) und d) wie kompetent der/die Verfasser*in ist (6-stufig), e) welche affektive Reaktion sie gegenüber dem Verfasser und f) für das Verkehrsmittel (9-stufig) empfinden. Vor und nach dem Vignettenmodul wurden neben soziodemografischen Charakteristika weitere Einstellungsfragen zu konventionellen und elektrischen Pkws gestellt.

Die empirisch gemessenen Einstellungen und experimentell hervorgerufenen Einstellungsänderungen wurden mittels eines PCS-Netzwerks modelliert. Alle zentralen Parameter der PCS-Modelle der Einstellungen der Teilnehmer:innen wurden auf Basis deren entsprechenden empirischen Ratings bestimmt. Die Computermodelle wurden in der Programmiersprache Java realisiert. Die statistischen Auswertungen des Experiments und die Berechnung der Veränderungen der Netzwerkgewichte im Zuge der Einstellungsveränderungen wurden in Python umgesetzt.

Studie 2

Zur Untersuchung der Einstellungen und Bewertungen neuer umweltfreundlicher Verkehrsmittel wurde eine deutschlandweite repräsentative Online-Umfrage durchgeführt. Die Rekrutierung der Teilnehmer:innen erfolgte auf Grundlage von bundeslandspezifischen Quotenvorgaben für die Merkmale Alter, Geschlecht, Bildungsstatus, Haushaltseinkommen, abgeleitet aus dem Mikrozensus (2011). Die Teilnehmerrekrutierung und die Datenerhebung wurden im Jahr 2016 durch das Marktforschungsinstitut Respondi AG durchgeführt.

Das Befragungsinstrument wurde für diese Studie neu konzipiert und basierte in Teilen auf zwei vorangegangenen vom Autor der Dissertation entwickelten Befragungsstudien zu Mobilitätsinnovationen (vgl. Wolf, 2016; Wolf & de Haan, 2013). Zentraler Untersuchungsgegenstand waren Einstellungen und Wahrnehmungen von konventionellen und modernen Verkehrsmitteln. Insgesamt wurden das Wissen und Interesse, die Überzeugungen und affektiven Reaktionen, die Nutzungsbereitschaft sowie soziale Normen zu fünfzehn unterschiedlichen Fortbewegungsformen untersucht. Darüber hinaus umfasste der Fragebogen fünf weitere Fragenblöcke: a) soziodemografische Merkmale, b) aktuelles Verkehrsverhalten (z. B. Nutzungshäufigkeit Verkehrsträger, Pkw-Besitz, Jahreskilometer Pkw), c) Nutzung sozialer Medien und spezifischer Apps zur Mobilitätsplanung, d) Priorisierung von Entscheidungskriterien der Verkehrsmittelwahl und e) diverse Persönlichkeitsmerkmale, die auf Basis standardisierter Erhebungsinstrumente oder Skalen gemessen wurden. Letzte Kategorie umfasste die Merkmale Risikobereitschaft (1 Item, 7-stufig; Beierlein, Kovaleva, Kemper, & Rammstedt, 2015), Lebenszufriedenheit (1 Item, 7-stufig; Beierlein, Kovaleva, László, Kemper, & Rammstedt, 2015), die Messung der allgemeinen Werthaltung nach dem Werte-Cirkumplex-Modell von Schwartz (1992) (Kurzskala, 10 Items 6-stufig, Boer, 2013), die subjektiv eingeschätzte Meinungsführerschaft nach Gnambs & Batinic (2011, 5 Items, 6-stufig), die allgemeine Innovationsbereitschaft in Anlehnung an die von Moons & De Pelsmacker (2015) entwickelte Skala (6 Items, 6-stufig) und die Parteiidentifikation (1 Item, 13-stufig). Alle Items der einzelnen Blöcke wurden in zufälliger Reihenfolge präsentiert.

Zur Datenauswertung und -analyse wurden die Statistiksoftwarepakete SPSS und R verwendet. Die Typenbildung erfolgte unter der kombinierten Anwendung einer hierarchischen (Ward-Algorithmus) und nichthierarchischen (K-Means-Algorithmus) Clusteranalyse. Als konstituierende Variablen der Segmentierung dienten die in drei affektiven Dimensionen vorliegenden Bewertungen aller untersuchten Verkehrsmittel.

Studie 3 und 4

Die Wechselwirkungen individueller Einstellungen, sozialer Einflüsse und (politischer) Interventionen zur Veränderung von Verkehrsmittelpräferenzen wurden mithilfe des agentenbasierten Modells (ABM) *InnoMind* analysiert. Agentenbasierte Modellierung ist ein computergestütztes Modellierungs- und Simulationsverfahren, das darauf abzielt, die Entstehung und voraussichtliche Entwicklung sozialer Phänomene (Makroebene) durch die Interaktion einer großen Anzahl autonom handelnder Agenten (Mikroebene) zu erklären und zu analysieren (Gilbert & Troitzsch, 2005). Ausgangspunkt der Simulationen sind softwarebasierte Modelle realer komplexer sozialer Systeme, die sowohl handelnde Akteure als auch deren Umwelt umfassen. Je nach Fragestellung und Forschungsgegenstand repräsentieren die Agenten in diesen Modellen Personen(-typen), Haushalte, politische Organisationen oder Unternehmen, die jeweils über spezifische Entscheidungsregeln verfügen. Die Umwelten, in denen sich die Agenten bewegen und handeln, können konkrete Repräsentationen beispielsweise städtischer Räume oder auch relativ abstrakte soziale Umgebungen wie zum Beispiel soziale Netzwerke sein. Im Zuge einer Simulation interagieren die Agenten miteinander und werden durch Merkmale und Veränderungen der (sozialen) Umwelt in ihrem Verhalten beeinflusst. Aus den Interaktionen und den Entscheidungen der Agenten entstehen *emergente* Phänomene und Strukturen – Systemzustände, die aus den Merkmalen der einzelnen Systembestandteile nicht direkt ableitbar sind, sondern durch die individuellen Handlungen der Agenten möglich werden, ohne dass diese auf das Verhaltensphänomen intentional hinwirken.

Die Modellierung komplexer (sozialer) Systeme mithilfe von ABM erfolgt in der Regel unter Rückgriff auf etablierte kognitions- und sozialwissenschaftliche Theorien. Wesentliche Voraussetzung für die Tauglichkeit theoretischer Ansätze ist neben inhaltlichen Aspekten deren Formalisierbarkeit. *InnoMind* basiert auf der Miko-, also Agentenebene, auf der Theorie emotionaler Kohärenz (Thagard, 2006). Die Einstellungen und Entscheidungen der Agenten wurden mithilfe von konnektionistischen PCS-Netzwerken bestehend aus Handlungsmotiven und -optionen, Überzeugungen und affektiven Bedeutungen modelliert. Die Informationsverarbeitungsprozesse werden in diesen neuronalen Netzwerken durch die Verbreitung von Aktivierungen repräsentiert (Details siehe Kap. 2.1). Zur Bestimmung der zentralen Parameter der individuellen PCS-Netzwerke in Studie 3 und 4 wurden die aus Studie 1 abgeleitete Lernfunktion beziehungsweise die im Rahmen des Projekts INNO-SIM gewonnenen Umfrageergebnisse verwendet (Wolf & de Haan, 2013).

Auf der Mesoebene werden in *InnoMind* soziale Netzwerkstrukturen nach dem Prinzip sozialer *Homophilie* – der Tendenz von Menschen, mit anderen Beziehungen einzugehen, die ihnen ähnlich sind – generiert (Burt, 1991; McPherson et al., 2001). Die Operationalisierung erfolgte auf zwei theoretisch zu unterscheidenden Mechanismen der Homophilie, nämlich der *Wahlhomophilie* und der *indizierte Homophilie* (siehe McPherson et al., 1987). Mit Wahlhomophilie sind homophile Beziehungen gemeint, die auf individuelle psychologische Präferenzen zurückgeführt werden können. Entstehen diese hingegen in Folge der Homogenität struktureller Interaktionsmöglichkeiten, wie zum Beispiel in Nachbarschaften, Freundeskreisen oder am Arbeitsplatz, wird dies als induzierte Homophilie bezeichnet. Der Mechanismus der Wahlhomophilie wurde in *InnoMind* unter Rückgriff auf das von (McPherson, 2004) vorgeschlagene *Blau-Space-Modell* formalisiert. Das Modell beruht auf der Idee, dass die soziale Position von Individuen in einem n-dimensionalen Raum dargestellt werden kann, in dem soziodemografische Merkmale wie Alter, Einkommen oder Bildung als Dimensionen dienen. Die entsprechenden individuellen Merkmale einer Person bestimmen ihre jeweilige Position im Blau-Space. Die euklidischen Abstände der in diesem Raum allokierten Personen wiederum beeinflussen deren Wahrscheinlichkeit, miteinander Verbindungen zu bilden – je geringer die Distanz, desto höher die Wahrscheinlichkeit. Zusätzlich wurde bei der Erstellung der sozialen Netzwerkstruktur in *InnoMind* die geografische Nähe berücksichtigt (indizierte Homophilie). Unter Rückgriff auf das von Hamill & Gilbert (2009) entwickelte Konzept der *Social Circle*s werden Beziehungen zwischen Agenten in Wohnumgebung mit einer höheren Wahrscheinlichkeit gebildet.

Die Implementierung des Modells erfolgte im ersten Schritt mithilfe des speziell für ABM-Anwendungen konzipierten Softwarepakets Netlogo. Aus Effizienzgründen wurde in einem zweiten Schritt die Anwendung in die Programmiersprache Java übersetzt. Der Programmcode ist unter https://www.comses.net/codebases/4973/releases/1.1.0/ verfügbar. Die Parametrisierung der zentralen Modellparameter, nämlich die Werte der PCS-Gewichte und die die soziale Netzwerkbildung konstituierenden Variablen, basieren auf der Onlineumfrage aus dem Jahr 2012 (vgl. Wolf & de Haan, 2013). Aus Ermangelung an geeigneten Daten war eine Validierung der Simulationsergebnisse mit unabhängigen Ergebnissen nicht möglich. Dennoch wurde die Plausibilität der Simulationsszenarien mit Expertinnen und Experten im Rahmen eines Workshops des Projekts INNO-SIM diskutiert.

5 Studie 1 – Mikroebene: The critical role of emotional communication for motivated reasoning

Wolf, I. & Schröder, T. (in Begutachtung). The critical role of emotional communication for motivated reasoning.

Der Artikel befindet sich momentan in Begutachtung bei der Fachzeitschrift Scientific Reports (Nature Publishing Group).

Abstract

Persuasive appeals often have a different effect than intended, due to motivated reasoning. This research explored how different levels of emotional content, valence of messages and the degree of coherence of pre-existing attitudes influence biased information processing. We used a vignette experiment (N = 480) in conjunction with a computational model of attitude formation, aimed at providing a better understanding of the cognitive-affective mircofoundations of motivated reasoning. The experimental results revealed that motivated reasoning was most evident for appeals using a combined emotional-rational and negatively valenced argumentation. Additionally, our model estimating levels of belief and affect adjustment underlying attitude changes explains the observed effects of messages framings by the mechanism of emotional coherence, and highlights the role of affect in motivated reasoning. The findings provide evidence for a negative association between coherence shifts in response to new information and the tendency of motivated reasoning.

Keywords

Motivated reasoning, attitudes, framing, persuasion, emotional coherence, affect, computational model

Introduction

In everyday life, people´s attitudes and reasoning are considerably influenced by emotions, cognitions and behaviours of other individuals. What we think about new technologies (Pettifor, Wilson, Axsen, Abrahamse, & Anable, 2017), political topics (Brady, Wills, Jost, Tucker, & Van Bavel, 2017) or scientific evidence (Guilbeaulta, Beckera, & Centola, 2018) often relies on the opinions of others. However, not every active attempt to change our attitudes, i.e. persuasive communication, affects us in the intended way. Beyond social factors such as cultural and group membership (Kahan et al., 2012), cognitive factors such as attitudinal congeniality (Hart et al., 2009) and affective coherence (Huntsinger, 2013) on issues have a tremendous impact on the strength of and response to social influence. When exposed to opposing arguments and feelings, individuals are prone to reinterpret and modify information so as to support their pre-existing attitudes and motives (Kunda, 1990). This tendency of motivated reasoning reflects the commitment to prior mental representations and might even create backfire effects by reinforcing existing biases (Zhou, 2016). Although crucial for understanding and modelling these individual effects on a group or societal level, little is known about the extent and direction of belief and affect adjustment, underlying observable attitudinal changes to persuasive appeals with varying levels of congruency.

Numerous empirical studies on motivated reasoning, also referred to in literature as biased assimilation or selective perception (Lord, Ross, & Lepper, 1979; Sherrod, 1971), offer in various domains abundant evidence that human information processing is constrained and motivated by existing beliefs and attitudes (Koehler, 1993), culturally induced values and ideologies (Kahan, Jenkins-Smith, Tarantola, Silva, & Braman, 2015) or religious worldviews (Ecklund, Scheitle, Peifer, & Bolger, 2017). Several strategies have been observed that people use to reach desired outcomes and to resist persuasive appeals; ranging from selectively avoiding information to discounting the source and negative emotional reactions (Jacks, Cameron, Jacks, & Cameron, 2003). Prolonged selective exposure to counterattitudinal messages may lead to an exacerbation of attitudinal polarization of social groups with opposing views in offline and online communication (Bail et al., 2018; Druckman, Peterson, & Slothuus, 2013). Within this literature, scholars have identified individual-level moderators relating to the internal structure of attitudes such as attitude strength (Taber & Lodge, 2006), factual knowledge (Druckman & Bolsen, 2011) and affective evaluation of concepts (Nisbet, Cooper, & Garrett, 2015) that shape the propensity to engage in motivated reasoning.

Theoretical work on information processing and attitude formation has explained motivated reasoning by people's desire to reduce inconsistencies in their beliefs and feelings, as well as to hold attitudes that satisfy their goals (Festinger, 1957; Kunda, 1990). This prior attitude mechanism is assumed to integrate new information automatically to foster the coherence of existing mental representations (Thagard, 2006). Localist connectionist models of mental reasoning show that coherence-driven mental processing of information can be computationally described as a parallel constraint satisfaction process (PCS; Thagard & Verbeurgt, 1998). Recent PCS models of attitudes provide a realistic, formalized account of complex structure and processes inherent to attitude change and a quantitative measure of coherence (Monroe & Read, 2008). However, existing approaches have been limited to formal theoretical models based on aggregated empirical or simulated data. Despite their explanatory power of a broad range of related phenomena, they lack detailed empirical data on a cognitive-affective level to make testable predictions about concrete mental structures that (dis-)encourage motivated reasoning under different directions of the advocacy ((in-)consistency of beliefs and affects) and nature of the argumentation (rational or more emotional) in persuasive communication. Moreover, most coherence models failed to explicitly consider the influence of affective processes associated with motivated reasoning known from empirical studies (e.g. Taber & Lodge, 2006).

Here we combine experimental data with computational modelling to investigate cognitive and affective processes underlying motivated reasoning in response to persuasive appeals. First, we designed an online vignette experiment that allowed us to analyse whether attitudinal reactions to persuasive appeals vary across different levels and valence of the emotional content of message frames and to test the hypothesis that motivated reasoning facilitates disfavouring of information source and attitude polarisation. Second, we simulated this process of information exchange and integration by specifying for each sender (i.e. vignette statement) and receiver (i.e. participants) a parallel constrained satisfaction network (PCS) model of their attitudes. PCS models capture the issue-specific representations as nodes (i.e., goals and attitude objects) and related links (i.e., beliefs and affective meanings). For each of the three experimental condition we estimate the adjustment of respondents' pre-existing network structures based on empirically reported attitude change. We identified specific mental structures and conditions most prone to motivated reasoning. Further, our approach enabled us to quantify the theoretically predicted increase of the overall coherence as result of motivated reasoning.

Experiment

Design

We conducted a factorial survey featuring statements advocating for or against the use of conventional (ICE cars) and electric cars (E-cars) to examine the relationship between pro- and counterattitudinal information and the tendency of motivated reasoning. Vignettes described attitudes and experiences of a hypothetical person arguing for or against conventional or electric cars. According to the experimental design of our main study we constructed three different types of fictive statements, i.e. a) vignettes with factual, goal-oriented argumentation, b) vignettes with emotional experiences with the different cars types, and c) vignettes arguing both goal-oriented and emotional. In each subgroup vignettes varied independently along four attributes including vehicle powertrain (i.e., internal combustion engine, electric engine), beliefs about contribution of vehicle types to domain-specific goals (i.e., independence, comfort, eco-friendliness, driving experience, good conscience), valence of attitude object (i.e. positive, negative). For each condition we constructed four sets of 10 vignettes by systematically combining the attributes, resulting in a total of 120 different vignettes. Each set contained five vignettes describing statements about conventional internal combustion engine (ICE) and five about electric cars, balanced in attitudinal valence. The respective vignette presented to a participant was randomly drawn out of the four vignette sets per condition, where each set was presented to 40 participants. Example vignettes of all three condition are provided in the Supplemental Material available online.

All vignettes were tested in a pilot study (N = 180) to ensure the salience of the specific characteristics of the three messages types (i.e., rational, emotional, combined). Participant of this study were recruited by Respondi AG and were randomized into one of three groups each comprising 40 respective vignette messages. We excluded five individuals due to incomplete data. The final sample of N = 175 of respondents (rational messages: N = 56; emotional messages: N = 59; combined messages: N = 60) indicated the emotionality and information content of each vignette on a six-point scales ranging from 'not at all' (1) to 'completely' (6). As expected, participants rated the rational messages as significantly more informative than the combined statements and the emotional ones (rational: $M = 3.58$, $SD = 0.09$; combination: $M = 3.19$, $SD = 0.08$; emotional: $M = 3.06$, $SD = 0.08$; $F(2,172) = 9.79$, $p < .0001$), but evaluated emotionally framed messages as having significantly more emotional content than combined and rational statements (emotional: $M = 4.23$, $SD = 0.10$; combined: $M = 4.13$, $SD = 0.10$; rational: $M = 3.80$, $SD = 0.1$; $F(2,172) = 5.36$, $p < 0.005$).

In the main study, four hundred eighty participants (47.1% female, age range 18-65 years, $M = 46.63$, $SD = 13.90$) were recruited and incentivized from a commercial online research panel in Germany (Respondi AG). All participants held a driving license and the majority (89.8 %) indicated to have at least moderate knowledge with respect to electric vehicles.

Using a between-subjects design, we assessed how people respond to different types of persuasive messages supporting the use of ICE cars and E-cars. Participants were randomly assigned to one of three experimental conditions: i) rational persuasion, comprising vignettes with factual, goal-oriented argumentation, ii) emotional persuasion, in which vignettes with emotional experiences with the different cars types were presented and iii) combined persuasion in which vignettes argued both goal-oriented and emotional. Each condition contained 160 individuals.

Before presenting the vignettes, participant's attitudes towards conventional (ICE cars) and electric cars (E-cars) were measured by 13 and 15 items respectively. The measures required respondents to indicate on a six-point Likert scale how much they agree with statements about how good the respective vehicle allows them to achieve their personal goals. Items of each transport mode were combined to a corresponding ICE car and E-car attitude scale and rescaled from -1 to +1. Each of the 10 vignettes was presented in random order on separate screens followed by six variables. Respondents were asked to answer questions about their a) level of *agreement* with the statements (1 = *strongly disagree*, 6 = *strongly agree*) to measure their dissonance with the messages, b) the *likability* of the author (1 = *very unpleasant*, 6 = *very likable*), c) the *competence* of the author (1 = *very low*, 6 = *very high*), both to quantify discounting of messages source, and d) whether their *attitudes* had *changed* into a more positive or negative direction after evaluating the persuasive message on a seven-point scale ranging from 'much more negative' (1) to 'much more positive' (7).

Results

We began our analysis by evaluating whether pre-treatment attitudes towards internal combustion engine cars (ICE car) and electric cars (E-car) differed across experimental groups. A one-way ANOVA showed no significant differences between groups for both attitude objects (ICE car: $F(1,318) = 0.0$, $p = .965$; E-car: $F(1,318) = 0.28$, $p = .600$). We therefore can confidently conclude that the following results are not driven by prior attitude differences between groups.

To examine the impact of prior attitudes on the evaluation of information (sources) and the subjectively perceived attitudes changes we used Pearson correlations. Fig. 1 (A-D) displays separately correlations between prior attitudes towards conventional and electric cars with each of the vignettes rating divided by positively and negatively framed messages. Note that analyses are aggregated across the three messages types. The agreement with statements was strongly related to participants prior attitudes (pos.: ICE car: $r = .58$, $p = .001$.; E-car: $r = .66$, $p = .001$; neg.: ICE car: $r = .49$, $p = .001$.; E-car: $r = .43$, $p = .001$). The results show strong motivated reasoning effects for both transport modes and message framings (positive/negative): Authors of messages that are closer to participant`s prior attitudes are evaluated as more likeable and competent than authors of information more distant to prior attitudes. Interestingly, we found evidence for a backfire effect. Attitude polarization (Fig. 1D), i.e. the shift and strengthening of attitudes among those holding strong prior attitudes in opposite direction of message valence, was much stronger for positive information (ICE car: $r = .30$, $p = .001$.; E-car: $r = .47$, $p = .001$), whereas negative messages about cars yielded no significant (ICE car: $r = .07$, $p =$ n.s.) and weak relation (E-car: $r = 0.15$, $p = 0.01$). Overall, correlations between prior attitudes and message judgments were stronger for positive statements than for negative ones. The same pattern was obtained for positively valenced messages about E-cars versus ICE cars, however, an inverted tendency for negative statements about the two different vehicle types.

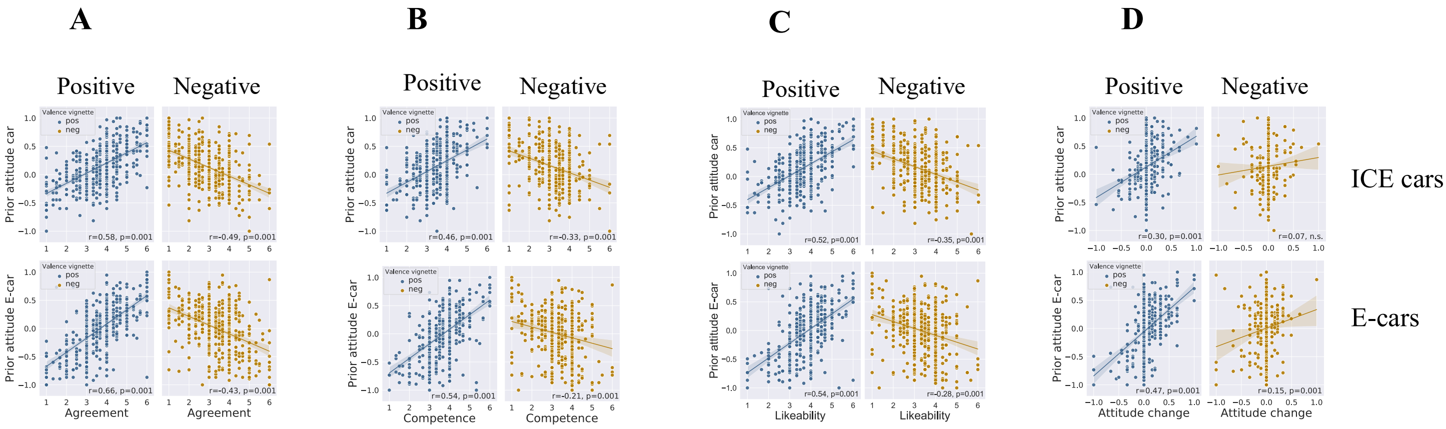

Figure 1. Correlation between prior attitudes and vignette responses

Correlations between prior attitudes towards conventional (upper panels) and electric cars (lower panels) and all vignette responses across conditions. Responses to positively valenced statements are plotted in blue and negatively valenced statements in gold. The solid lines are the correlation lines and shaded areas indicate a 95% CI. (A) Prior attitudes correlated with agreement to statements. (B) Prior attitudes correlated with the perceived competence of the sender of statements. (C) Prior attitudes correlated with the likeability of the sender. (D) Prior attitudes correlated with the self-reported attitude change.

Next, we analysed the effects of the different types of positive and negative persuasive messages separately. Fig. 2 (A-D) displays average responses to all vignettes related measures broken down by condition and valence. Consistent with the view that positive messages are more appealing and persuasive than negatively valenced ones (Nordmo & Selart, 2015), participants' ratings were, on average, significantly higher for positive information. Separate dependent *t* tests showed significant differences across all three conditions regarding the agreement with the statements (rational: $t(159) = 6.50$, $p < .001$; emotional: $t(159) = 4.56$, $p < .001$; combined: $t(159) = 6.88$, $p < .001$), the competence of the sender (rational: $t(159) = 5.88$, $p < .001$; emotional: $t(159) = 4.83$, $p < .001$; combined: $t(159) = 7.76$, $p < .001$), the likability of the sender (rational: $t(159) = 6.06$, $p < .001$; emotional: $t(159) = 6.96$, $p < .001$; combined: $t(159) = 8.69$, $p < .001$), and the perceived attitude shift in response to the information (rational = $t(159) = 5.69$, $p < .001$; emotional: $t(159) = 2.60$, $p < .01$; combined: $t(159) = 4.24$, $p < .001$).

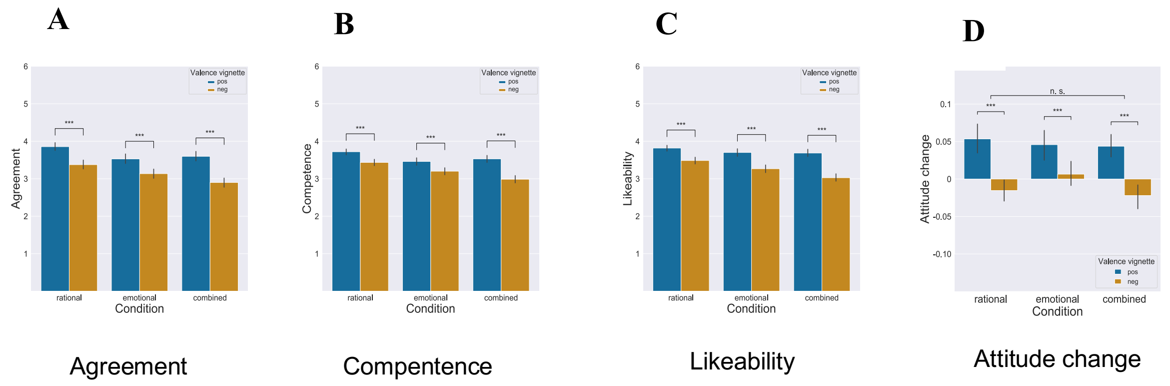

Figure 2. Mean ratings on all vignette responses across conditions

Mean ratings on all vignette responses across conditions by experimental condition and valence of statements (blue: positive valence; gold: negative valence). Error bars display the standard error of the mean. (A) Agreements to vignettes. (B) Perceived competence of sender. (C) Likability of sender. (D) Self-reported attitude change

Comparing the effects of different types of persuasive appeals with respect to perceived attitude changes (Fig. 2D) using one-way ANOVA with Tukey´s HSD post-hoc test (p <.05), we found no significant differences neither across groups nor in all in pairwise comparisons between groups neither for positive messages (F(2,477) = 0.15, p = .8590, η_p^2 = .0003) nor for negatives (F(2,477) = 1.80, p = .166, η_p^2 = .0006). In contrast, the analysis of evaluations concerning senders' characteristics yielded significant effects across all types of persuasive appeals. Participants indicated for rational statements the highest levels of agreement (pos.: F(2,477) = 8.85, p = .001; neg.: (F(2,477) = 13.45, p = .001), senders' competence (pos.: F(2,477) = 7.23, p = .0001, η_p^2 = . 029; neg.: F(2,477) = 19.40, p = .001, η_p^2 = .075) and of likability (pos.: F(2,477) = 2.36, p = .10, η_p^2 = .009; neg.: F(2,477) = 20.04, p = .001, η_p^2 = .077) for both positive and negative message framings. Responses to emotional information was slightly but not significantly more positive than to the combined condition, shown by the post-hoc test.

Finally, an additional analysis of covariance (ANCOVA) controlling for perceived dissonance (i.e. agreement), prior attitudes toward ICE and E-cars and the two-way interactions between these control variables and the treatment, however, revealed a more nuanced picture. The main effect of message type on perceived attitude change is slightly significant (pos.: F(2,477) = 3.29, p = .0379, η_p^2 = 0.014; neg.: F(2,477) = 3.80, p = .0231, η_p^2 = .016). The covariates prior attitudes towards E-cars (pos.: F(1,478) = 9.32, p = .0024, η_p^2 = .019; neg.: F(1,478) = 11.34, p = .0008, η_p^2 = .019) and the agreement with the statement had a significant effect on perceived attitude change (pos.: F(1,478) = 215.83, p = .0001, η_p^2 = 0.312; neg.: F(1,478) = 45.23, p = .0001, η_p^2 = .087), whereas prior attitudes to ICE cars had no significant influence (pos.: F(1,478) = 0.76, p = .7829, η_p^2 = .018; neg.: F(1,478) = 0.93, p = .3352, η_p^2 = .017). Moreover, results also revealed a small but significant interaction between message type and agreement for negative ($F(2,477) = 3.80$, $p = .0023$, $\eta_p^2 = .018$) and (not significant) for positively valenced statements ($F(2,477) = 2.15$, $p = .117$, $\eta_p^2 = .009$). For participants more dissonant with the information perceived the combined messages as most persuasive. In contrast, when respondents showed more agreement with the statements, rationally and emotionally framed messages produced stronger attitude changes.

Parallel constraint satisfaction model of motivated reasoning

Model structure

In our experiment, the process of motivated reasoning, i.e. the tendency of respondents to interpret and evaluate information in a way protecting their existing attitudes, is clearly visible. However, the results raise the question as to which underlying cognitive-affective structures and mechanisms facilitate the process and to what extent these structures are modified if attitudes change. Therefore, we analyzed the observed effects by developing a computational model of attitude formation and change based on the parallel constraint satisfaction (PCS) theory of emotional coherence (Thagard, 2006). In general PCS is the connectionist conceptualization of cognitive consistency and has its roots in well-known theories of cognitive dissonance (Festinger, 1957) and congruity theory (Osgood & Tannenbaum, 1955). Connectionist models assume that information processing is constrained by a network of prior beliefs and goals. New evidence is integrated automatically by a parallel spread of activations in this symbolic network in such a manner as to maximize the number of satisfied constraints, i.e. the desire or motive to minimize inconsistencies and to arrive a conclusion maintaining prior beliefs and affect. Various simulation studies have shown that motivated reasoning can be thought of as a process of parallel constraint satisfaction (e.g. Monroe & Read, 2008).

We implemented the experimental set-up as a directional communication between two PCS models – a sending (i.e., vignette statement) and a receiving agent (i.e. respondent), both equal in their general network structure. The process comprises four steps, illustrated in Fig 3B. Our starting point is a PCS network representation of respondents' attitudes. Its generic structure comprises the three interrelated constructs of attitudes: cognitive (i.e. beliefs about the relationship between goals and action options), affective (i.e. feelings about goals and action options) and conative (i.e. behavioural tendencies regarding an action option) components (Ajzen, 1989). In localist models such as PCS networks, psychological concepts (i.e. goal or action) are represented as units and the links between the units denote the relationships between the concepts (i.e. beliefs or feelings). Our model, shown in Figure 3A, consists of a general activation node (leftmost) and three layers of nodes (units) representing valence (second from left; i.e. feeling of (un-)pleasantness), goals (third from left, i.e. motives of transport mode choice) and action options (rightmost, i.e. transport modes). Mutual constraints between concepts are represented as bidirectional links between nodes of each layer.

Connections between goals and option nodes can be either excitatory, representing supportive beliefs (e.g., the personal goal of comfort is facilitated by the use of an E-car) or inhibitory, denoting contradictory beliefs (e.g., the personal goal of environmentally responsible travel behavior is not supported by the use of an ICE car). Links between valence and goal or options units indicate positive (excitatory) or negative (inhibitory) affective associations of concepts. The strength of beliefs or affect is represented by connection weights that vary from -1.0 to 1.0. Lines connecting the general activation and the goal units indicate the personal importance of a goal, weighted between 0 and 1.0. Here, the PCS network of each agent consists of five goal nodes (i.e. independence, comfort, eco-friendliness, driving experience, good conscience) and two option nodes representing attitudes toward the use of ICE and E-cars. Based on this structure, attitudes of each participant (n = 480) were modeled as a unique PCS model and parameterized by using their individual survey responses regarding the importance of goals, beliefs, and affective meanings of concepts. All other model parameters were similar to our previous studies (cf. Wolf, Schröder, Neumann, & de Haan, 2015).

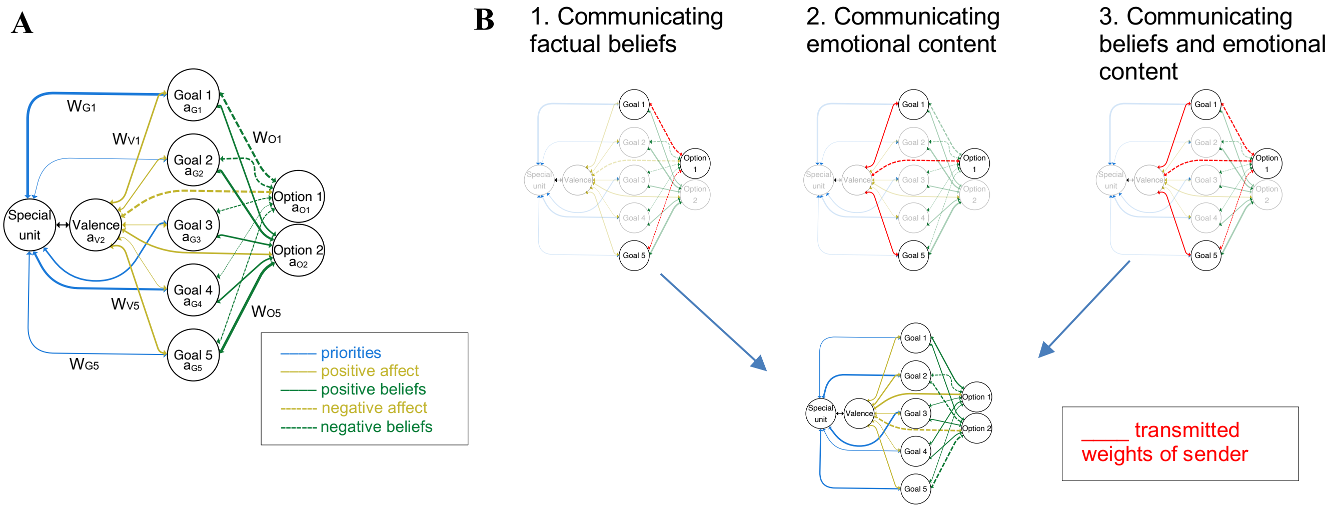

Figure 3. Parallel constraint satisfaction model (PCS) of attitude formation and change

(A) General PCS model of attitudes towards transport modes. Nodes in the network symbolize (from left to right), beyond a special unit for activating the spreading algorithm, the valence existing concepts, personal goals and the options of action in a mobility context. Links between the valence, goal and option nodes represent the affective association of concepts. Positive feelings are shown by solid lines and negative ones by dashed lines. Connections between goal and option nodes represent beliefs. Positive beliefs are displayed by solid lines and negative ones by dashed lines. All link weights are determined by the empirical ratings of participants in vignette experiment, described above in the main text. (B) Model of information transmission in vignette experiment for each experimental condition. In the rational condition (1.) connection weights of beliefs, in the emotional condition (2.) weights of affective associations, and in the combined condition (3.) weights of both beliefs and affective associations expressed in the respective vignette are transmitted to the receiver (i.e. PCS network model of participants' attitude.

An iterative updating algorithm spreading activations through the network simulates the process of attitude formation as a process of coherence maximisation considering all constraints in a given network structure (McClelland & Rumelhart, 1981). At time t = 0 all nodes start at an activation close to zero, except the general activation node, which is set to 1.0. Activation of units are repeatedly updated in parallel until they converge on a stable pattern of activation and their degree of change is below a certain threshold. Activations are updated according to the following equation:

$$a_j(t+1) = \begin{matrix} a_j(t)(1-d) + \{net_j[\max - a_j(t)]\} \text{ } if \text{ } net_j > 0 \\ \{net_j[a_j(t) - min)]\} \text{ } if \text{ } net_j \leq 0 \end{matrix}, \quad (1)$$

where a_j(t) is the activation of the unit j at iteration t. The constant parameter d (0.05) is the rate of decay of activation for each unit at every cycle, *min* is the minimum activation (-1.0) and *max* is the maximum activation (+1.0). The incoming activation from other nodes is computed by the connection weight w_{ij} between each unit i and j, the net input net_j to a node

$$net_j = \sum_i w_{ij} a_i(t). \quad (2)$$

Updating is repeated until stable levels of activation is reached and the network has settled, usually after less than 100 iterations. The final activation of option nodes represents the evaluation of an object, whereby (high) positive values indicate a (strong) positive attitude and (high) negative values a (strong) negative attitude. At this point the overall coherence of the network (Energy; Hopfield, 1984; Hopfield, 1982) is calculated by:

$$Energy(t) = -\sum_i \sum_j w_{ij} a_i a_j \quad (3)$$

Where w_{ij} is the weight between each unit i and j, and a_i (t) is the activation of unit i at time (t). According to this equation, if the sign of the product of the activation of two units is coherent with the sign of constraint between them, energy decreases; in contrast, if the sign of the product of activation of two nodes is inconsistent with the constraint between them, energy increases. The overall coherence of the network is high if all cognitive and affective elements connected to one option fit together but not to the second option. In contrast, if beliefs and affect associated with both options are equally inconsistent, i.e. both option units are linked to a similar number of excitatory and inhibitory weights, attitudinal ambivalence makes it more difficult to favour one option and decreases coherence.

In a second step, we specified the network representation of persuasive messages using the same PCS model shown in Fig. 3a. To this end, we transferred the particular characteristics of each individual vignette statement as weighted constraints of the network. For example, connection weights of a persuasive appeal to use e-cars (o_1) emphasising that this transport mode meets the goals of environmentally friendly (g_1) and comfortable (g_2) travel behaviour, were set in the following way: links between goals and e-car option nodes (w_{g1-o1}, w_{g2-o1}) as well as between valence, goals and e-car option nodes ($w_{v\text{-}g1}$, $w_{v\text{-}g2}$, $w_{v\text{-}o1}$) were initialized with +1.0, where all other weights were set to 0.01. In contrast to the PCS model of respondents as described above, the process of attitude formation is not simulated here because activations of nodes are not relevant for the subsequent process of information exchange.

In the third step, we implemented the three modes of persuasive communication, i.e. experimental conditions, as a transfer of different types of information or rather network elements between sender and receiver (see Fig. 3b). In the rational persuasion mode, specific link weights between goal and option nodes (i.e. beliefs) corresponding to the argumentation of the respective vignette text were communicated. In the mode of emotional persuasion, connection weights between valence and goal as well as valence and option nodes (i.e. affective meanings) were transmitted. The information transfer of the third mode, combined persuasion, comprised both type of weights (i.e. beliefs and affective meanings) of the preceding mechanisms. Overall, we generated, corresponding to the experimental procedure, simulations for 10 unique persuasive attempts per receiving agent, resulting in a total of 4800 (1600 per condition) simulated vignette treatments.

In the last step, we modelled adaptation of attitudes resulting from persuasive messages as weight changes in receivers' network structure. In contrast to previous learning models for PCS networks, weight adjustments were specific in the sense that only links transmitted by the sender in the respective conversation and condition were modified in receivers' networks. For example, in a rational persuasive communication about the use of e-cars comprising positive arguments regarding the comfort and eco-friendliness of this transport mode exclusively connections between the goal units comfort and eco-friendliness and the option unit e-car were changed. Drawing on literature on network learning (Read & Urada, 2003; Rescorla & Wagner, 1972), we applied a variant of the error-correcting learning rules to modify link weights as a function of the degree of error between simulated and empirically reported changed attitudes. Adjustments were calculated by means of a standard backpropagation algorithm to minimize the total sum squared error function *D* over all vignette treatments defined as:

$$D=\frac{1}{N}\sum_{i}^{N}\left(A_{sim}-A_{emp}\right)^{2} \qquad (4)$$

where A_{sim} represents the activation of the respective option unit in response to new information i.e. receivers simulated attitude towards a transport mode. A_{emp} is the empirically reported attitude after vignette treatment, calculated as by respondents' original attitude plus the self-reported attitude change, which has been rescaled to values ranging between -1 and +1. N is the total number of simulated vignette treatments.

The minimization of the error function is achieved by fitting free parameters to the following equation.

$$\Delta w = b_1 \Delta w_{s,r} + b_2 w_r + b_3 \Delta w_{s,r} w_r + b_4 w_r^2 + b_5 \Delta w_{s,r}^2 \quad (5)$$

where b_i are the parameters systematically iterated in in given upper and lower limits of -1 and +1. $\Delta w_{s,r}$ is the difference (i.e. dissonance) between the corresponding link weights of sender and receiver, i.e. the difference between existing beliefs and affects and new information. w_r is the connection weight in the PCS network of the receiver before communication. The function also includes the interaction between $\Delta w_{s,r}$ and w_r and is approximated up to quadratic order. Best fitting parameters ($b_{1\text{-}5}$) were estimated by iterating systematically through the set free parameters in the permitted range between -1.0 and +1.0.

Simulation results

Based on the parameterised PCS models, we performed a simulation of each respondents' attitude before message influence occurred. To test whether our model captures the empirically measured attitude pattern prior to persuasion attempts, we correlated the activations of option nodes for ICE car and E-car with the corresponding self-reported attitudes of respondents. These results showed a high resemblance between simulation and empirical findings (ICE car: $r = 0.93$, $p = 0.001$; E-car: $r = 0.93$, $p = 0.001$). In addition, the relation between simulated coherence of networks, i.e. the energy of PCS networks, and respondents' simulated prior attitudes across conditions, showed an inverted U-shape pattern (Fig. 4A), also supported by the results of quadratic regression models for ICE cars ($R^2 = .50$, $F(1, 478) = 476.4$, $p < .001$) and for E-cars ($R^2 = .57$, $F(1, 478) = 631.7$, $p < .001$). As predicted by the PCS approach, both strongly negative and positive prior attitudes were associated with low levels of energy, indicating attitudes to be consistent, stable and resistant to change. Fig. 4B depicts the average empirical measured agreement to statements (i.e. dissonance) for each condition and the corresponding coherence obtained from the simulations. The results reveal a similar inverted U-shaped pattern as the one reported above for prior attitudes (rational pos.: $R^2 = .14$, $F(1, 318) = 50.59$, p < .001; rational neg.: R2 = .05, F(1, 318) = 16.48, p < .001; emotional pos.: R2 = .10, F(1, 318) = 36.52, p < .001; emotional neg.: R2 = .05, F(1, 318) = 16.86, p < .001; combination pos.: R2 = .23, F(1, 318) = 93.79, p < .001; combination neg.: R2 = .08, F(1, 318) = 30.23, p < .001). Across experimental conditions and for positively and to a somewhat lower degree for negatively valanced messages, high and low agreement is associated with low levels of energy, whereas for medium agreement energy reached the highest levels. Thus, as one might expect, individuals with low attitudinal ambivalence, i.e. greater coherence, tend to show higher (dis-)agreements to (counter-)pro-attitudinal positions.

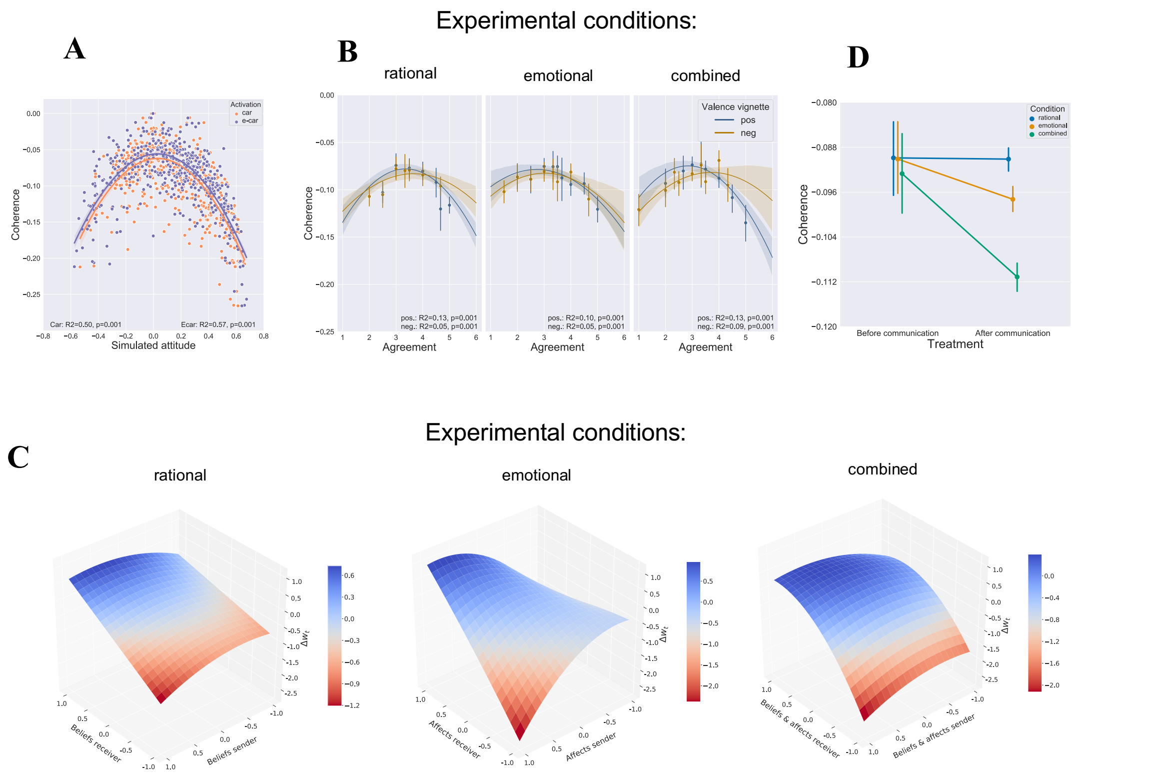

Figure 4. Computational model results

Note in general low levels of energy indicate a high degree of coherence. (A) Correlation of simulated attitudes for conventional (orange) and electric cars (blue) with simulated coherence, i.e. level of energy, of PCS network models for all simulated persuasive appeals. The solid lines are the correlation lines and shaded areas indicate a 95% CI. (B) Regression of empirical measured agreement to statements for each condition and the corresponding simulated coherence of PCS networks. Solid lines (blue: positively valenced; gold negatively valenced) are the best-fit regression lines. For the sake of better readability of the graph, empirical ratings of agreement are aggregated in bins. The error bars show the 95% CI. (C) Average weight changes of beliefs and affect link calculated based the observed attitude changes for each condition. For PCS networks in the rational condition error function D is minimized for free parameters $b_1 = 0; b_2 = 0.7, b_3 = -0.3, b_4 = 0\ b_5 = -0.3,$ in the emotional condition for the parameters $b_1 = 0; b_2 = 0.7, b_3 = -0.3, b_4 = 0.3\ b_5 = -0.7$ and in the combined condition where $b_1 = 0; b_2 = 1.0, b_3 = -0.3, b_4 = 0.7\ b_5 = -0.3.$ (D) The average coherence level of PCS networks before and after the treatment for each condition.

But to what extent are the cognitive-affective structures underlying attitudes modified by persuasive messages conveying different levels of emotionality? Fig 4C shows the average weight changes (Δw) of beliefs and affect in each experimental condition that minimize the respective error functions D, i.e. the difference between simulated and measured attitudes after persuasive communication. The results indicate across conditions varying patterns of belief and affect convergence and divergence. Depending on the strength and valence of receivers' prior beliefs/affect as well as their distance to the ones of the sender, weights are adjusted in heterogenous ways. When, for example in the rational condition, sender and receiver hold very strong opposing (sender: w_s = +1.0/-1.0 and receiver w_r = - 1.0/+1.0) (prior) beliefs, receivers update their beliefs opposite to the new information, increasing the strength of his or her prior belief. However, this occurs to varying degrees for receiving agents with prior positive and with negative beliefs. Interestingly, this back-fire effect in response to opposing positive information evokes higher negative weight adjustments than beliefs changes in response to negative messages consistent with previously held negative beliefs. In contrast, when sender support receivers' prior beliefs, weights are updated in the direction of the sender.

Both the effect of belief polarization/convergence and valence asymmetry is most pronounced when two agents merely exchange affect, in the emotional condition and to a somewhat lower degree in the combined condition. In the emotional condition, however, opposing negative messages (i.e. receiver hold strong positive affects) had no polarizing effect and lead to a convergence of posterior affect towards the message.

To identify the effects of weights adjustments in response to persuasive messages on the coherence of PCS networks, we compared the average energy levels of all agents before and after the treatment for each condition (Fig. 4D). Before receiving persuasive messages there was no significant difference of coherence levels between conditions ($F(2,477) = 0.19$, $p = .8824$, $\eta^2 = .001$). The information exposure resulted in a statistically significant decrease of energy in the emotional and combined, but not in the rational condition ($F(1,479) = 410.96$, $p = .0001$, $\eta^2 = .0462$). These findings suggest, as predicted by the process of coherence maximization, that beliefs and affect are adjusted in a way that increases the coherence among existing mental representations. Interestingly, this effect is most pronounced when combined rational and emotional communication is used.

Discussion

The first goal of this research was to examine the effects of different levels of emotional content of persuasive messages on motivated reasoning. We showed that motivated reasoning affects regardless of message framing the persuasiveness of statements and leads, when confronted with counterattitudinal positions, to dissonance with the statement and discounting of the source of information. Moreover, we provided evidence that motivated reasoning can create backfire effects causing people to strengthen their existing attitudes in the opposite direction of persuasive appeals, in particular for individuals with strongly held views and high dissonance, replicating prior research (e.g. Nyhan & Reifler, 2010). Our novel finding was that this process was moderated by the message type and valence of the advocated positions. Biased reasoning was most evident when participants were faced with negative (vs. positive) framed appeals and using combined rational and emotional tone (vs.

exclusively rational or emotional). The persuasiveness of messages was negatively related to the degree of motivated reasoning. Additionally, our results indicated that impact of motivated reasoning on source perceptions was mainly determined by dissonance (agreement) with persuasive appeals and less so by prior attitudes.

Our second goal was to explain the observed effects with the computational mechanisms of emotional coherence by extending an existing parallel constraint satisfaction (PCS) model (Thagard, 2006) with a learning algorithm. Our simulation results revealed that modifications of existing mental representations underlying attitude changes vary substantially across valence and different message types. Consistent with prior experiments (Bizer & Petty, 2005) we found that negative affect and beliefs are more resistant to counterattitudinal persuasive attempts. Additionally, we show that negative mental structures have a stronger tendency to cause backfire effects, most pronounced when threatened by emotionally positive appeals. Our findings suggest that mental structures respond and integrate information varying in emotional quality and intensity differently. Recent neuroimaging studies support the view that positively and negatively framed information is coded differently in the brain and unequally used to update prior affect and beliefs (cf. Sharot & Garrett, 2016).

Prior research on PCS models (e.g. Glöckner & Betsch, 2008) assuming coherence maximization as the core mechanism of information integration argued that this process automatically operates to increase the coherence of existing mental representations. Using a more realistic learning PCS network model, we complement these previous studies by providing evidence that the level of coherence shift associated with attitude changes is determined by the type of mental structure involved in information integration. Information affecting merely the cognitive structures of attitudes resulted after updating beliefs in no increase in overall coherence. In contrast, when information involved affective and in particular both affective and cognitive elements of attitudes, the state of global coherence was increased significantly. The findings highlight the role of affect to reduce dissonance and attitudinal ambivalence toward options for action and support the proposition that decision and attitude formation are performed by maximizing the emotional coherence of mental structures – cognitions and affect - involved in the decision at hand (Thagard, 2006). Moreover, the pattern of coherence shifts that is inversely related to the observed tendency of motivated reasoning suggests an effortful process underlying the integration of new information, in particular when both strong cognitive and affective components of attitudes are involved. The greater the effort a person needs to invest to come up with a coherent conclusion the lower the persuasiveness and credibility of the messages source. Future research could integrate additional elements such as specific identity concepts into the model, thus further investigating the interaction between the processing goal of attitude-protective and the goal of identity-protective both moderating the responses to new information.

Our findings contribute to a growing literature on the role of motivated reasoning in information processing and attitude formation. Earlier studies of the effects of biased processing of evidence and persuasive appeals focused on the influence of belief strength, values and political or group identity on attitude responses and group polarization (cf. Druckman & McGrath, 2019). We complement this work by showing that positively valanced and cognitively framed messages can reduce the reasoning bias and avoid polarization between communication partners. Our results suggest that reducing emotionally engaging content for messages that run counter to beliefs and affects of individuals, but increasing the emotional level of persuasive appeals when their information is congruent with the representation of the respondent, may offer a useful strategy to increase the effectiveness of persuasive communication and avoid backfire effects.

Moreover, our research contributes to the field of computational models of opinion dynamics and social influence (e.g. Flache et al., 2017). The findings illustrate the importance of studying and understanding the microfoundations of the processes underlying motivated reasoning. Our modelling framework demonstrates how existing theoretical (agent-based) models of attitude and opinion formation can be extended to include psychologically more realistic processes underlying information processing and can be based on empirical support. We anticipate that our approach opens new avenues for future work that aims to identify how individual reasoning affects dynamics on a populational level. From a practical perspective, for example in policy contexts of mobility transition, such an approach would allow to better understand how policy makers can communicate policy problems and to accelerate public understanding of available evidence and facilitate discussion towards informed policy (e.g. Schröder & Wolf, 2017; Wolf et al., 2015).

Acknowledgements

This research was funded by the German Federal Ministry for Education and Research (BMBF) (#16I1660 and #16I1659). Reproduced with permission from Springer Nature.

Supplement Material

Vignette examples for the experimental conditions rational, emotional and combined.

Figure A1 shows the English translation of a vignette example in the rational persuasion condition, Figure A2 an vignette example in the emotional persuasion condition and Figure A3 presents an example of a vignette in the iii) combined persuasion condition, in which vignettes argue both goal-oriented and emotional.

When I decide on a suitable means of transport for everyday life, it is important to me that I can travel comfortably and in an environmentally friendly way. The car satisfies my need for environmentally friendly mobility, as I can also drive in an environmentally friendly way if I drive it in the right way. In addition, today's cars offer me great comfort due to their modern equipment. All in all, the car meets all my requirements and I can only recommend that you drive it.

Fig. A1. Example vignette for rational condition. Attributes: vehicle powertrain: internal combustion engine car; goals: environmental friendliness, comfort; valence of attitude object: positive

Driving's great! After work come down first. In the comfortable ambience of my car I can always relax wonderfully and enjoy the way home. I don't even know what they all have: Fuel-efficient driving or even better, completely doing without the car, is nonsense. God knows there are worse environmental sinners than car drivers.

Fig. A2. Example vignette for emotional condition. Attributes: vehicle powertrain: internal combustion engine car; goals: environmental friendliness, comfort; valence of attitude object: positive

Driving a car is just fun! It satisfies my need for comfort like no other means of transport and is for me an environmentally friendly form of mobility. After work, get in the car and come down first. In the comfortable ambience of my car I can always relax wonderfully. I don't even know what they all have: Fuel-efficient driving or even better, completely doing without the car, nonsense. God knows there are worse environmental sinners than car drivers. For me, the car is the perfect means of transport, and I think it's the best for you too!

Fig. A3. Example vignette for combined condition. Attributes: vehicle powertrain: internal combustion engine car; goals: environmental friendliness, comfort; valence of attitude object: positive

References

Ajzen. (1989). Attitudes structure and behavior. In A. R. Pratkanis, S. J. Breckler, & A. G. Greenwald (Eds.), Attitude Structure and Function (pp. 241–274). Hillsdale, NJ: Erlbaum.

Bail, C., Argyle, L., Brown, T., Bumpus, J., Chen, H., Hunzaker, M. B., … Volfovsky, A. (2018). Exposure to opposing views can increase political polarization: evidence from a large-scale field experiment on social media. Proceeding of the National Academy of Scienes, 117(37), 9216–9221. https://doi.org/10.17605/OSF.IO/4YGUX

Bizer, G. Y., & Petty, R. E. (2005). How we conceptualize our attitudes matters: The effects of valence framing on the resistance of political attitudes. Political Psychology, 26(4), 553–568. https://doi.org/10.1111/j.1467-9221.2005.00431.x

Brady, W. J., Wills, J. A., Jost, J. T., Tucker, J. A., & Van Bavel, J. J. (2017). Emotion shapes the diffusion of moralized content in social networks. Proceedings of the National Academy of Sciences, 114(28), 7313–7318. https://doi.org/10.1073/pnas.1618923114

Druckman, J. N., & Bolsen, T. (2011). Framing, motivated reasoning, and opinions about emergenttechnologies. Journal of Communication, 61(4), 659–688. https://doi.org/10.1111/j.1460-2466.2011.01562.x

Druckman, J. N., & McGrath, M. C. (2019). The evidence for motivated reasoning in climate change preference formation. Nature Climate Change 2019, 9, 111–119. https://doi.org/10.1038/s41558-018-0360-1

Druckman, J. N., Peterson, E., & Slothuus, R. (2013). How elite partisan polarization affects public opinion formation. American Political Science Review, 107(1), 57–79. https://doi.org/10.1017/S0003055412000500

Ecklund, E. H., Scheitle, C. P., Peifer, J., & Bolger, D. (2017). Examining Links Between Religion, Evolution Views, and Climate Change Skepticism. Environment and Behavior, 49(9), 985–1006.https://doi.org/10.1177/0013916516674246

Festinger, L. (1957). The theory of cognitive dissonance. California: Stanford University Press.

Flache, A., Mäs, M., Feliciani, T., Chattoe-Brown, E., Deffuant, G., Huet, S., & Lorenz, J. (2017). Models of Social Influence: Towards the Next Frontiers. Journal of Artificial Societies and Social Simulation, 20(4), 2. https://doi.org/10.18564/jasss.3521

Glöckner, A., & Betsch, T. (2008). Modeling option and strategy choices with connectionist networks : Towards an integrative model of automatic and deliberate decision making. Judgment and Decision Making, 3(3), 215–228.

Guilbeaulta, D., Beckera, J., & Centola, D. (2018). Social learning and partisan bias in the interpretation of climate trends. Proceeding of the National Academy of Scienes, 115(39), 9714–9719. https://doi.org/10.1073/pnas.1722664115

Hart, W., Albarracín, D., Eagly, A. H., Brechan, I., Lindberg, M. J., & Merrill, L. (2009). Feeling Validated Versus Being Correct: A Meta-Analysis of Selective Exposure to Information. Psychologcial Bulletin, 135(4), 555–588. https://doi.org/10.1037/a0015701.Feeling

Hopfield, J. J. (1984). Neurons with graded response have collective computational properties like those of two-state neurons. Proceedings of the National Academy of Sciences, 81, 3088–3092. https://doi.org/10.1073/pnas.81.10.3088

Hopfield, John J. (1982). Neural networks and physical systems with emergent collective computational abilities. Proceeding of the National Academy of Scienes, 79(April), 2554–2558. https://doi.org/10.1201/9780429500459

Huntsinger, J. R. (2013). Incidental Experiences of Affective Coherence and Incoherence Influence Persuasion. Personality and Social Psychology Bulletin, 39(6), 792–802. https://doi.org/10.1177/0146167213482588

Jacks, J. Z., Cameron, K. A., Jacks, J. Z., & Cameron, K. A. (2003). Strategies for Resisting Persuasion. Basic and Applied Social Psychology, 25(2), 145–161. https://doi.org/10.1207/S15324834BASP2502

Kahan, D. M., Jenkins-Smith, H., Tarantola, T., Silva, C. L., & Braman, D. (2015). Geoengineering and Climate Change Polarization: Testing a Two-Channel Model of Science Communication. Annals of the American Academy of Political and Social Science, 658, 192–222. https://doi.org/10.1177/0002716214559002

Kahan, D. M., Jenkins-Smith, H., & Braman, D. (2011). Cultural cognition of scientific consensus. Journal of Risk Research, 14(2), 147–174. https://doi.org/10.1080/13669877.2010.511246

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. Nature Climate Change, 2(10), 732–735. https://doi.org/10.1038/nclimate1547

Koehler, J. J. (1993). The Influence of Prior Beliefs on Scientific Judgments of Evidence Quality. Organizational Behavior and Human Decision Processes. https://doi.org/10.1006/obhd.1993.1044

Kunda, Z. (1990). The case for motivated reasoning. Psychological Bulletin, 108(3), 480–498. https://doi.org/10.1037/0033-2909.108.3.480

Lord, C. G., Ross, L., & Lepper, M. R. (1979). Biased assimilation and attitude polarization: The effects of prior theories on subsequently considered evidence. Journal of Personality and Social Psychology, 37(11), 2098–2109. https://doi.org/10.1037/0022-3514.37.11.2098

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part I. An account of basic findings. Psychological Review, 88, 365–405.

Monroe, B. M., & Read, S. J. (2008). A general connectionist model of attitude structure and change: the ACS (Attitudes as Constraint Satisfaction) model. Psychological Review, 115(3), 733–759.

Nisbet, E. C., Cooper, K. E., & Garrett, R. K. (2015). The Partisan Brain: How Dissonant Science

Messages Lead Conservatives and Liberals to (Dis)Trust Science. Annals of the American Academy

of Political and Social Science, 658(1), 36–66. https://doi.org/10.1177/0002716214555474

Nordmo, M., & Selart, M. (2015). The asymmetrical force of persuasive knowledge across the positive–negative divide. Frontiers in Psychology, 6, 1324. https://doi.org/10.3389/fpsyg.2015.01324

Nyhan, B., & Reifler, J. (2010). When corrections fail: The persistence of political misperceptions. Political Behavior, 32(2), 303–330. https://doi.org/10.1007/s11109-010-9112-2

Osgood, C. E., & Tannenbaum, P. H. (1955). The principle of congruity in the prediction of attitude change. Psychological Review, 62(1), 42–55.

Pettifor, H., Wilson, C., Axsen, J., Abrahamse, W., & Anable, J. (2017). Social influence in the global diffusion of alternative fuel vehicles – A meta-analysis. Journal of Transport Geography, 62(July), 247–261. https://doi.org/10.1016/j.jtrangeo.2017.06.009

Read, S. J., & Urada, D. I. (2003). A neural network simulation of the outgroup homogeneity effect. Personality and Social Psychology Review, 7(2), 146–169.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), Classical onditioning II: Current research and theory (pp. 65–99). New York: Appleton-Century-Crofts.

Schröder, T., & Wolf, I. (2017). Modeling multi-level mechanisms of environmental attitudes and behaviours: The example of carsharing in Berlin. Journal of Environmental Psychology, 52, 136– 148. https://doi.org/10.1016/j.jenvp.2016.03.007

Sharot, T., & Garrett, N. (2016). Forming Beliefs: Why Valence Matters. Trends in Cognitive Sciences, 20(1), 25–33. https://doi.org/10.1016/j.tics.2015.11.002

Sherrod, D. R. (1971). Selective Perception of Political Candidates. Public Opinion Quarterly, 35(4), 554. https://doi.org/10.1086/267951

Taber, C. S., & Lodge, M. (2006). Motivated Skepticism in the Evaluation of Political Beliefs. American Journal of Political Science, 50(3), 755–769. https://doi.org/10.1080/08913811.2012.711019

Thagard, P. (2006). Hot thought: Mechanisms and applications of emotional cognition. Cambridge, MA: MIT Press.

Thagard, P., & Verbeurgt, K. (1998). Coherence as Constraint Satisfaction. Cognitive Science, 22(1), 1– 24. https://doi.org/10.1207/s15516709cog2201_1

Wolf, I., Schröder, T., Neumann, J., & de Haan, G. (2015). Changing minds about electric cars: An empirically grounded agent-based modeling approach. Technological Forecasting & Social Change, 94, 269–285. https://doi.org/10.1016/j.techfore.2014.10.010

Zhou, J. (2016). Boomerangs versus Javelins: How Polarization Constrains Communication on Climate Change. Environmental Politics, 25(5), 788–811. https://doi.org/10.1080/09644016.2016.1166602

6 Studie 2 – Mesoebene: Connotative meanings of sustainable mobility: A segmentation approach using cultural sentiments

Veröffentlicht als:

Wolf, I., & Schröder, T. (2019). Connotative meanings of sustainable mobility: A segmentation approach using cultural sentiments. *Transportation Research Part A: Policy and Practice*, *126*, 259–280. https://doi.org/10.1016/j.tra.2019.06.002

Abstract

Changing people's travel behaviours and mode choices is an important mitigation option to reduce greenhouse gas emission in transport. Previous studies have shown that symbolic meanings associated with new low-emission vehicles and travel services influence people's willingness to adopt these innovations. However, little is known about the symbolic meanings of many upcoming transport innovations, which often influence habitual decision-making and their stratification within the population. This study thus examines cultural affective meanings of a broad range of conventional and novel transport mode options in a nationally representative German sample. Cluster analysis of affective meanings of travel modes identified six unique traveller segments. These consumer groups differ significantly in their intention to adopt low-emission travel modes and are characterized by specific psychographic, socio-demographic and behavioural profiles. The results demonstrate that affective meanings of choice options are predictive regarding the attitudes and (intended) behaviour of traveller segments. Moreover, the invariant positive meanings of conventional cars across segments indicate the strong cultural embeddedness of this mode in society. We discuss the implications of our approach for the development of government strategies for sustainable transport.

Keywords

Affective meanings, symbolic meanings, sustainable travel behaviour, segmentation, social marketing, transport innovations

Introduction

The transition to sustainable mobility is key to reduce the current level of energy use and to mitigate climate change. Transport accounts for around 24% of global carbon dioxide (CO_2) emissions, making it the second largest CO_2 emitting sector (IEA, 2017). Emission levels are growing rapidly and have been projected to double globally by 2050 (IPCC, 2014). Even in regions such as the European Union and the United States, where transport-induced emissions have stabilized in recent years, current demand growth in fuel-inefficient car segments (e.g. SUVs) as well as the expected increase in passenger and freight road transport urgently necessitate effective strategies to decarbonize the transport system (Creutzig et al., 2015; Gössling & Metzler, 2017). Promoting the shift to more efficient new transport technologies and services, such as electric vehicles or ridesharing, has been highlighted in literature as an important pathway for change (Bento AM, Hughes JE, 2013; Chan & Shaheen, 2012; Chapman, 2007; Tran, Banister, Bishop, & McCulloch, 2012). However, despite existing policies encouraging the adoption of these innovations, their uptake is lagging in many countries behind expectations (Adnan, Nordin, Rahman, Vasant, & Noor, 2017; EDTA, 2018; EVWSD, 2018; Wang, Li, & Zhao, 2017). It is becoming increasingly clear that a deeper understanding of social and cultural contexts of peoples' choices, including the impact of heterogenous, socially shaped preferences, and meanings associated with existing travel practices, is central to effectively encouraging people to change their lifestyles and travel behaviours (Creutzig et al., 2016; Dietz, Leshko, & McCright, 2013; Gatersleben, 2014; Oyserman, 2017; Pettifor, Wilson, Axsen, Abrahamse, & Anable, 2017; Steg et al., 2015). Indeed, these previously neglected aspects of mitigation policies on people's social environments will be also featured and highlighted in the upcoming IPCC sixth assessment report (AR6) (cf. Creutzig, Roy, Lamb, Azevedo, & Bruin, 2018).

Designing tailored interventions and communication strategies requires detailed knowledge about motivators that drive travel mode choices and more generally the adoption of pro-environmental behaviour by specific groups of consumers (Abrahamse, Steg, Vlek, & Rothengatter, 2007; Cairns et al., 2008). Although a growing body of research demonstrated that besides financial incentives, various non-instrumental factors, such as values, symbolic motives, and affect play an important role in peoples' willingness to engage in pro-environmental travel behaviours (Barbarossa, De Pelsmacker, & Moons, 2017; Chng, Abraham, White, Hoffmann, & Skippon, 2017; Innocenti, Lattarulo, & Pazienza, 2013; Nordlund & Garvill, 2003; Nyborg et al., 2016; Steg, Vlek, & Slotegraaf, 2001), in policy design, assumptions that humans' decisions are governed by maximizing economic benefits are still common (Mattauch, Ridgway, & Creutzig, 2015; Schwanen, Banister, & Anable, 2011). These types of mechanisms, however, cannot fully explain observed heterogeneity in response to economic measures of fuel efficient vehicles (Jenn, Springel, & Gopal, 2018; Vergis &

Chen, 2015) and corresponding instruments couldn´t generate a continuing rise in their demand (Biresselioglu, Demirbag Kaplan, & Yilmaz, 2018; Langbroek, Franklin, & Susilo, 2016). Recent work showed that factors such as symbolic attributes of new transportation technologies, e.g. electric vehicles (EVs), are strong complementary predictors of adoption intention (e.g. Noppers, Keizer, Bolderdijk, & Steg, 2014; Oliver & Lee, 2010). Theoretical assumptions suggest that people interpret symbolic attributes by relying on culturally shared implicit affective meanings and sentiments associated with these objects (Heise, 2007; Neil J. MacKinnon & Heise, 2010). Despite a broad intracultural consensus, empirical work revealed significant differences in cultural affective meanings for specific concepts within sub-populations of society (Ambrasat et al., 2014). A better knowledge of affective associations related to new ecofriendly travel alternatives and their variations among sub-populations in society thus may provide valuable information for targeted and more effective campaigns encouraging more sustainable transport.

Yet, little is known about affective meanings attached to transport modes and their heterogeneity and/or consensus across different social groups in society. In particular, empirical studies concerning emotional associations people attach to the wide variety of existing and upcoming new travel options and their relationship to attitudes and adoption intentions are lacking. This study aims to address this gap by adopting a social psychological approach to assess cultural affective meanings of a broad range of travel options in a large-scale sample of the German population. We start by reviewing the main approaches and findings on the effects of symbolic meanings attached to transport mode choices and corresponding segmentation models of travellers. We then propose a parsimonious yet effective segmentation approach based on affective sentiment ratings. We describe the profiles of segments with respect to a comprehensive set of psycho-, sociodemographic, and behavioural characteristics, as well as consumers' willingness to adopt new travel options. Finally, we discuss how tailored communication strategies could take into account group-specific patterns of affective meanings associated with transportation modes, which offer a deeper understanding of how implicit cultural knowledge affects (adoption) decisions.

Literature review and theoretical concepts

Different aspects of symbolic meanings

According to symbolic interactionism, people interpret the social world based on cultural symbols, and human behaviour is a function of meanings individuals ascribe to symbols (Blumer, 1986). Symbolic meanings of objects, identities and behaviours include both deliberate cognitive denotations and automatic affective connotations (Barthes, 1967; Finegan, 2008). Denotative meanings describe the explicit aspects as well as obvious, socially shared cognitive images associated with a concept.

For instance, the denotative meanings of cycling are: e.g. zero-emission transport mode, physical effort, and additionally, protecting the environment. Connotative, affective meanings, in contrast, refer to the implicit, intuitive and emotional processes associated with concepts. They contain implicit social and cultural knowledge, elicit specific emotional responses and constrain people's choice of behaviours (Neil J. MacKinnon & Heise, 2010; Schröder, Stewart, & Thagard, 2013). Thus, in the previous example, affective meanings of bike riding may elicit affective response patterns linked to emotions such as joy or aversion and activate corresponding action tendencies (Schröder & Wolf, 2018).

Studying the relationship between symbolic meanings attached to products, identities, and consumption behaviour has a long tradition in consumer research and has received increasing attention in understanding the motivators of pro-environmental behaviour in recent years (Oyserman, 2009; Reed, 2002; Sirgy, 2018; van der Werff, Steg, & Keizer, 2013a; Whitmarsh & O'Neill, 2010). With few exceptions (Coleman & Williams, 2013; McGowan, Shiu, & Hassan, 2017; Shank & Lulham, 2016a), the majority of work has focused on the effects of predefined denotative meanings of identities and products on behaviour, but less so on the influence of more implicit affective meanings of these representations. In transport research disparate streams of literature draw on various theoretical underpinnings from (social) psychology and sociology to investigate the link between symbolic denotative attributes and behavioural choices (cf. Rezvani, Jansson, & Bodin, 2015). The theories and applications differ in their approaches to conceptualization and measurement of symbolic meanings and their central mechanisms of behaviour.

Denotative symbolic meanings of travel behaviour

In one of the first studies examining beyond functional utility, symbolic motives of mode choices, Steg (2005) showed that the frequency of car use is mainly driven by the perceived symbolic and affective attributes of this mode. As a theoretical basis, Steg (2005) proposed the psychological model of material possession by Dittmar (1992). According to this, people's intentions to use material goods depend on the product evaluation of three aspects: their functional utility, affective value, and symbolic meaning. In this view, symbolic values serve to express a persons' identity and values as well as social status or membership of a group. The categorial framework has been adopted and adapted by many others researchers to study different aspects of travel behaviour (cf. Gatersleben, 2014; Hunecke, 2015). Recent research on the adoption of electric vehicles (EV), for example, showed that symbolic meanings mediate perceived instrumental attributes of EVs and also influence the intention to adopt these vehicles (e.g. Morton, Anable, & Nelson, 2016; Schuitema, Anable, Skippon, & Kinnear, 2013; White & Sintov, 2017). Although counterintuitive, this effect was more pronounced for early adopter groups when they perceived more instrumental drawbacks of ecofriendly technologies (Noppers, Keizer, Bockarjova, & Steg, 2015). Some researchers have criticized the ambiguous and inconsistent definition of relevant concepts of the approach, making it difficult to dissociate and compare respective results across studies and samples (cf. Murtagh, Gatersleben, & Uzzell, 2012; White & Sintov, 2017). Moreover, motivational categories of this approach seem not distinct but rather overlapping psychological constructs (Lois & López-Sáez, 2009).

A second line of research has assessed the relation of symbolic attributes of travel modes and behaviour referring to the self-congruity theory (Sirgy, 1986). Sirgy posits that consumer behaviour is driven by self-congruity, a psychological process in which individuals compare their perceived product-image with different facets of their self-image (i.e. actual, ideal, and social, self-concepts). Each dimension of a persons' self-concept in turn is motivated by a specific need (i.e. need for self-consistency, self-esteem, social consistency, and social approval). The theory predicts that consumers' motivation to purchase and use products is strongest when perceived product-images correspond positively with self-images and fulfill the corresponding needs of an individual. A large body of empirical research corroborated the theoretical assumptions both for pre-purchase behaviour such as attitudes towards and intentions to adopt certain travel modes such as EVs (e.g., Kressmann et al., 2006; Noppers et al., 2015, 2014; Oliver & Lee, 2010; Schuitema et al., 2013; Skippon, Kinnear, Lloyd, & Stannard, 2016), and for post-purchase behaviour such as satisfaction and vehicle use (e.g. Jamal & Al-Marri, 2007; for review across domains see Sirgy, 2018). While these analyses demonstrated the psychological relevance of predefined symbolic meanings of certain transport modes for isolated aspects of self-concepts, e.g. a pro-environmental identity, they did not account for potentially competing meanings of manifold behavioural options in transport and their link to multiple (social) identities people have in their real life, as emphasized by sociological theorists (e.g. Burke & Stets, 2009).

Not much literature in transport research draws on the symbolic interactionist tradition of identity theory to explore relations between symbolic meanings, identity and travel behaviour. Murtagh et al., (2012) examined the importance of multiple identities on mode choices in regular travel adopting the sociological identity theory by Stryker (1980). They found evidence that a range of identities predict mode choices and that the pattern of relation varies across types of journey. Barbarossa, Beckmann, De Pelsmacker, Moons, & Gwozdz (2015) showed positive effects of meaning of a "green" self-identity (Whitmarsh & O'Neill, 2010) on attitudes towards and intentions to adopt electric cars drawing on the theoretical framework of identity control theory (Burke & Stets, 2009). Theoretical frameworks of identity consider self-identity as a set of meanings that locate a person in certain social roles in society (Burke & Stets, 2009; Stryker, 2008). They follow the central premise of symbolic interactionism (Blumer, 1986) that people act toward the world not based on its physical properties but based on socially shared meanings, which emerge from social interaction with others (see above). In this view, meanings act as a reference of self-perception, influence the expectations of others, and guide individuals' behaviour in given situations. The described empirical studies contributed to better understanding the mechanisms and effects of denotative meanings attached to multiple personal and social identities on travel behaviour. They did not, however, examine the influence of symbolic meanings inherent in travel modes themselves on travel mode choices and behaviour.

Connotative symbolic meanings

Explicit denotative symbolic association of new technologies and behaviours take time to be formed in the social environment (Heffner, Kurani, & Turrentine, 2007). Especially, when behaviour options are unfamiliar and novel people often rely upon affective meanings of concepts as a guide to decision making and attitude formation (Lerner et al., 2015; van Giesen, Fischer, van Dijk, & van Trijp, 2015). Connotative, affective meanings can be conceptualized on three dimensions: evaluation (good-bad), potency (powerful-powerless) and (lively-inactive) (Osgood, May, & Murray, 1975; Osgood et al., 1957). Ratings on these dimensions reflect generalized affective responses to symbols that are widely shared within a culture or subgroups of a society (Heise, 2010; Neil J. MacKinnon & Heise, 2010). Moreover, these dimensions correspond to the basic foundation of communication and social interaction (Scholl, 2013). Shank & Lulham (2016a) showed by drawing on Affect Control Theory (ACT, Heise, 2007) that affective connotations of consumer goods function as modifier of persons' identities. ACT builds upon the central principles of symbolic interactionism (SI) of meaning-making (see section 2.1.1). In contrast to traditional SI approaches, ACT presumes that people's actions and interpretation of the social world rely on generalized *affective* responses to cultural symbols. These affective responses are referred to as cultural sentiments that are trans-situationally quantified. As a central mechanism of behavioural control, the theory assumes that people strive to maintain cultural sentiments about their own identities and other entities in a given situation. Moreover, the theory provides a mathematically formalized framework to predict behaviours and emotions in a given situation. Following the argument by Shank & Lulham (2016b), we propose that the theoretical coneptualization of ACT provides a framework to understand the influence of symbolic connotative meanings of technologies on adoption behaviour and in addition, a coherent theoretical basis to select variables relevant to identify travel segments of more sustainable transport options. Further details we will explain below in the methods section.

Symbolic meanings and segmentation models

Audience segmentation approaches, one of the central methods of social marketing to promote behavioural change for social benefit (cf. Corner & Randall, 2011; McKenzie-Mohr, 2002), have been adopted in various domains such as health (e.g. Mathijssen, Janssen, van Bon-Martens, & van de Goor, 2012), energy and water use (e.g. Poortinga & Darnton, 2016), climate change (Maibach et al., 2011), and transport (e.g. Prillwitz & Barr, 2011) for the design of targeted and tailored interventions. These studies often use a combination of domain- or issue-specific socio-, psychographic, and/or behavioural variables to identify different subpopulations (cf. Haustein & Hunecke, 2013; Hine et al., 2014). In transport research, attitude-based segmentation models have been shown to be most useful to reveal varying motives and barriers of transport modes choices (Haustein & Hunecke, 2013).

Among the numerous attitudinal segmentation approaches developed for promoting travel behaviour change only a few involve symbolic meanings and affective responses towards mode choice options. Jensen (1999) assessed in a combined qualitative and quantitative approach symbolic aspects of car use. Based on interview results she defined six types of travellers' and found attitudinal differences between groups in the perception of cars as symbols of freedom and independence. Cools, Moons, Janssens, & Wets (2009) used Q-methodology to categorize a small sample of respondents into traveller groups with distinctive preferences for cars and public transport. They assessed a set of motivational statements including symbolic-affective items considering aspects of self-expression and social prestige attached to cars. In contrast to Jensen (1999), they found the most prevalent differences between the four groups in instrumental motives of model choice and a high agreement in the symbolic meanings of cars. These inconsistent results may be due to missing theoretical rigor of segmentation models (Bösehans & Walker, 2018; Dibb & Stern, 1995).

Some studies have illustrated the potential of theory-driven segmentation models to travel behaviour. For example, Hunecke, Haustein, Bohler, & Grischkat (2010) conceptualized traveller types based on an expanded version the Theory of Planned Behaviour (TPB, Ajzen, 1991). TPB was operationalized for conventional transport modes with a combination of attitudes - including symbolic aspects such as autonomy, excitement, status, and privacy - norms, and values. Hunecke et al. identified five traveller groups that differed significantly in terms of their travel-mode choice, distances traveled, and ecological impact. The results concluded that segments with equally strong preferences for private motorized modes but opposing symbolic evaluations of private cars require specific interventions and services to encourage a shift to more sustainable modes of transport. TPB has been critiqued, however, for its tendency to over-rationalize decision processes, neglecting the influence of affective, habitual and contextual factors of transport mode choices (Burgess, Harrison, & Filius, 1998; Pronello & Camusso, 2011).

Other researchers proposed more integrated theoretical segmentation frameworks, incorporating multiple theoretical constructs and mechanisms to behaviour change and adoption of new technologies. Anable, Skippon, Schuitema, & Kinnear (2012) developed a theoretically based segmentation model by means of thorough exploratory analysis of factors influencing vehicle adoption. In a follow-up study they applied this model comprising 14 psychological factors (for details see Anable, Kinnear, Hutchins, & Skippon, 2016) to a large sample of UK residents aiming to identify groups in the population willing to adopt electric vehicles (EVs). They distinguished eight distinct segments differing in terms of their perceptions, emotional reactions and symbolic motives related to EVs. Interestingly, the results indicate that symbolic meaning attached to EVs are a better predictor of vehicle adoption intention than economic motives and one of the defining characteristics of the segments. These results have been supported by finding of similar multi-factorial segmentation approaches for EVs (McLeay, Yoganathan, Osburg, & Pandit, 2018; Morton et al., 2017). The tendency of people to send signals to one another that highlight their personality traits (Miller, 2009), however, can be both conducive or impeding for the uptake of EVs. Skippon & Garwood (2011) showed that for early adopters EVs signal their openness, and that they care about others. For other traveler groups intending to indicate their wealth and social status small and short range EVs might have a negative symbolic meaning.

Overall, the findings corroborate the idea that symbolic meanings attached to technologies and behaviours potentially cause people to adopt these options, because their specific meanings correspond or mismatch with their self-identities as well as modify and express their intended self-image vis-a-vis relevant others (Oyserman, 2009; Reed, Forehand, Puntoni, & Warlop, 2012; Shank & Lulham, 2016a; Solomon, 1983). Segmentation research showed that symbolic meanings attached to travel choices varies among subgroups of populations and corresponds to their specific travel preferences and behaviours. Most of the segmentation models, however, lack a coherent theoretical basis, with a few notable exceptions (e.g., Anable, 2005; Bösehans & Walker, 2018; M. Hunecke et al., 2010) and are mostly focused on specific transport modes (e.g cars, EVs, public transport). Symbolic meanings have been defined and operationalized somewhat inconsistently across studies capturing different aspects of (denotative) meanings and are sometimes confused with other psychological constructs (e.g. emotions).

The present study

This research contributes to the existing literature in the following ways. First, we suggest a parsimonious yet comprehensive assessment of connotative meanings of travel modes by using a universal measurement system of Osgood' et al. (Osgood et al., 1975, 1957). Mapping the meanings of different choice options (i.e. travel modes) in the same three-dimensional affective space allows for a quantitative comparison and clustering of objects with different denotative symbolic attributes. Second, assessing connotative meanings of concepts in this way provides a theory-based specification of the segmentation model and a theoretical understanding of how variation of symbol meanings in society affect current and intended behaviour (cf. Heise 2007; Schröder & Thagard, 2013). In contrast to previous segmentation studies in transport often using a mixture of different psycho-social variables, we segmented the sample by applying cluster analysis exclusively based on affective meanings of travel mode options. We hypothesized that the identified segments vary significantly in terms of their willingness to adopt low-emission travel options. In addition, we profiled the identified groups of travellers in Germany on a broad range of characteristics and distinctive features. Third, we extend prior work of market segmentations for specific transport innovations, by including beyond the conventional transport modes–i.e. internal combustion engine car, public transport, bicycle and walking–different upcoming travel options–i.e. electric cars with varying degrees of electrification, electric bikes, several autonomous vehicle concepts and different carsharing services. Finally, by developing such a comprehensive cross-technology segmentation model, we aimed at supporting the German government in the design of strategies tailored to specific characteristics of targeted groups, that encourage the change towards more sustainable travel behaviour.

Method

Study participants

We conducted an online survey with sample of N = 5.948 respondents representative for the German population aged between 16 and 69 years. Participants were recruited via the online panel provider Respondi AG using quotas for age, gender, educational level, and household income based on the German Micro Census (MC). The final sample (see far-right column, Table 2) comprised 50.8% women (MC = 50.7%), had a mean age of 43.86 years (SD = 15.16) (M_{MC} = 43.01 years) and an average household size of 2.44 persons (M_{MC} = 2.0 persons). 26.2% of these households lived with at least one child (MC = 28.0%). The respondents in the current study were slightly better educated and more likely to reside in larger cities (> 500.000 inhabitants) i.e., 20% of the sample (MC = 18.7%) and comprised a lower proportion of households (26.7%) with low incomes (up to 1500 € per month) than the German population (MC = 30%). The rate of driving license owners among participants was 85.8% (German population = 87%; Infas, DLR, & IVT 2018) and the number of households with at least one car per household was 83.4% (German population = 78%; Infas et al., 2018).

Survey instrument

The survey instrument was developed to identify variations in affective meanings of a broad range of traditional as well as upcoming sustainable modes of transportation across subgroups of the German population and to assess their cognitive attitudes und intentions to adopt these transformative mobility technologies and services. The selection of transport innovations was based on a comprehensive literature research about upcoming transportation services and technologies in the next 10-15 years. For a comprehensive characterization of subgroups, the survey comprised beyond the segmenting items – i.e., affective meanings of verbal concepts related to transportation – five additional sections investigating a) cognitive attitudes towards modes of transportation, b) importance of transport mode attributes c), indicators of current travel behaviour, d) personal characteristics such as political ideology, value orientation, innovativeness, opinion-leadership, individual tendency of risk-taking and life satisfaction as well as e) socio-economic and demographic characteristics of respondents.

Segmentation variables

Affective meaning ratings of four verbal concepts denoting traditional (e.g., internal combustion engine car) and eleven novel transport mode options (i.e., autonomous vehicle for public transport) were obtained on nine-point semantic differential scales along the dimensions evaluation (*E*), potency (*P*) and activity (*A*) (*EPA,* cf. Osgood et al., 1957; Osgood & Tannenbaum, 1955). Respondents were instructed to evaluate each transport option (e.g. "internal combustion engine car") based on three questions, which refer to the three connotative dimensions of languages, i.e. evaluation (*E*), potency (*P*), and activity (*A*): (*E*) How good/bad is this transport mode? (*P*) How powerful/powerless is this transport mode? and (*A*) How exciting/calm is this transport mode? These verbal concepts were presented in random order and respondents used bipolar adjective scales labelled with corresponding verbal end-anchors "bad/unpleasant" and "good/pleasant" for judgments of evaluation, "weak/powerless" and "strong/powerful" for potency, and "calm/slow" and "exciting/fast" for activity. Scale points between the two extreme categories were labeled identically on both sides of the "neutral" center-point (0) – i.e. from "slightly" (+/-1), "quite" (+/-2), "very" (+/-3), and "extremely" (+/-4).

Validation variables

Given the different stages of development and availability of the investigated sustainable transport innovations, each mode was explained to the participants before we examined various attitude measures – i.e. cognitive attitudes, adoption intention as well as knowledge of and prior experience with the innovation. Unless stated otherwise, belief items were measured on a 6-point Likert scale ranging from 'applies completely' to 'does not apply at all'. Self-reported *knowledge* was rated on

6-point scale form 'no knowledge' to 'I´m an expert', the item measuring the degree of *experience* with the new mode choices ranged from 'no experience' to 'I own it/ I use it every day'.

Belief-based *cognitive attitudes* were assessed by eight items reflecting psychological attributes relevant for travel mode choices. The attributes (i.e., independence/flexibility, comfort, cost efficiency, environmental friendliness, safety, driving experience, time efficiency, expression of personality & lifestyle) were selected based on prior work (Hunecke et al., 2010) and informed by our own empirical work, where we conducted five focus groups to explore the motives of travel modes choices (Wolf & de Haan, 2013). For each innovation, respondents were asked to indicate on a six-point scale to what extent they believed that using the transport mode would meet their need for each attribute (form 'not at all' to 'completely)'. For each mode of transport, attitude scales were formed by averaging responses to the 8 items. Participants also completed a three-item measure of *adoption intention* of transport innovations. It included questions about i) their interest in and ii) their willingness to substitute the current main mode with the new transport option in question, and iii) how likely it is that they will use or buy the innovation in the near future (on an 11-point scale from 0% to 100%). The adoption-intention score was computed by averaging the standardized score of the three items.

The general *importance of attributes* when choosing a mode of transportation (see previous paragraph) was measured by asking respondents to evaluate each attribute on a 6-point scale from 'extremely unimportant' to 'extremely important'.

Indicators of everyday *travel behaviour* included self-reported frequencies of use of traditional transport modes and various *mobile travel services* such as renting bicycles or buying tickets for public transport on a 5-point scale from '(almost) every day' to '(almost) never'. Participants were also asked to report the number of cars per household, average distance travelled per year by conventional internal combustion engine (ICE) car, possession of a driver's license and the ownership of weekly, monthly, and seasonal tickets for public transport. If no car use was indicated, reasons for renunciation of car ownership were obtained using a categorical item (i.e., 'no need for a car', 'conscious renunciation', 'too expensive', 'for health reasons', 'for age reasons', 'other reasons').

We assessed various *personal characteristics* that had been found in previous work related to the adoption of pro-environmental behaviours. *Political ideology* was measured with one item asking participants to indicate the political party in Germany they most identify with (categories: conservative Christian Democratic Party (CDU)/ Cristian Social Party (CSU), Social Democratic Party (SPD), Green Party (Bündnis 90/ Die Grünen), Pirate party (Piraten), Left-wing Party (Die Linke), Liberal Democratic Party (FDP) and the nationalistic protest party Alternative for Germany (AfD). Using a short version of the Schwartz value orientation scale (Boer, 2013) respondents further indicated the importance of 10 different *value* constructs on a 6-point scale ranging from 'extremely unimportant' to 'extremely important'. Peoples' *innovativeness* was measured by using six items inspired by the innovativeness scale from Moons & De Pelsmacker (2015) asking respondents about their agreement with statements such as 'I like to have new experiences and changes in my daily routine' on a 6-point Likert scale. The average of responses to these items represents the innovativeness measure (Cronbach's α =.87). Items adopted from the Generalized Opinion Leadership Scale (Gnambs & Batinic, 2011) were rephrased to target the specific aspects of *opinion leadership* in the domain of mobility (e.g., 'My friends and acquaintances often discuss subjects that I brought up' or 'I usually want to convince people in my social circle if I'm enthusiastic about a mobility innovation'). Computing the mean score of the five items resulted in a reliable opinion leadership scale (Cronbach's α =.86). Individual tendency of *risk-taking* and *life satisfaction* were obtained using one-item scales from Beierlein, Kovaleva, László, Kemper, & Rammstedt (2015).

Finally, participants provided *socio-demographic* information (age, sex, education level, labour market status, income level, household size, number of children in the household, duration of living in current residence).

Results

Segmentation analysis

To classify respondents into subgroups with homogeneous affective meanings of concepts denoting traditional and novel modes of transportation we used a combined hierarchical (Ward's algorithm) and nonhierarchical cluster analysis (*k*-means algorithm). The segmentation analysis was conducted based on ratings of 15 transport modes (interval-level scale is assumed) along the dimension evaluation (E), potency (P) and activity (A), resulting in a total of 45 items. During analysis, the number of cluster solutions was limited to 3 to 8 segments to ensure interpretability and practical usefulness. The final cluster solution of six clusters, shown in Table 1.1-1.3, was chosen by applying the elbow criterion, i.e. plotting explained variance against the number of clusters. Every cluster has a considerable sample size, shows specific transport preferences, mental representations and personal characteristics according to which we labeled each segment (see footnote in Table 1).

Table 1. Evaluation ratings of transport modes for each segments and total sample

	Cluster							
	1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)	Total Sample	*p*

Transport mode	Evaluation							
ICE	1.72_{3} (1.93)	$1.57_{3,6}$ (1.81)	$0.91_{1,2,4,5,6}$ (1.72)	$1,74_{3}$ (1,91)	$1.49_{3,6}$ (1.91)	$1.89_{2,3,5}$ (2.06)	1.39 (1.87)	<.001
PT	$1.92_{2,3,4,5,6}$ (1.63)	$0.01_{1,3,4,6}$ (1.95)	$0.29_{1,2,4,5,6}$ (1.75)	$-1,00_{1,2,3,5}$ (2,11)	$0.03_{1,3,4,6}$ (2.07)	$-0.99_{1,2,3,5}$ (2.46)	0.12 (2.08)	<.001
BI[c]	$2.61_{2,3,4,5,6}$ (1.42)	$1.57_{1,3,4,6}$ (1.70)	$0.92_{1,2,5,6}$ (1.79)	$0,69_{1,2,5,6}$ (2,23)	$1.68_{1,3,4,6}$ (1.86)	$0.23_{1,2,3,4,5}$ (2.58)	1.26 (1.98)	<.001
OF	$2.68_{2,3,4,5,6}$ (1.33)	$1.64_{1,3,4,5,6}$ (1.80)	$1.33_{1,2,4,5,6}$ (1.73)	$1,01_{1,2,3,5}$ (2,18)	$1.93_{1,2,3,4,6}$ (1.81)	$0.91_{1,2,3,5}$ (2.45)	1.55 (1.91)	<.001
HEC	$2.34_{2,3,4,5,6}$ (1.39)	$1.84_{1,3,4,5,6}$ (1.30)	$0.,03_{1,2,4,5,6}$ (1.08)	$0,39_{1,2,3,5,6}$ (1,69)	$0.87_{1,2,3,4,6}$ (1.62)	$-3.05_{1,2,3,4,5}$ (1.42)	0.58 (1.91)	<.001
BEC	$2.37_{2,3,4,5,6}$ (1.34)	$1.77_{1,3,4,5,6}$ (1.39)	$-0.01_{1,2,5,6}$ (1.22)	$0,14_{1,2,5,6}$ (2,00)	$0.71_{1,2,3,4,6}$ (1.75)	$-3.29_{1,2,3,4,5}$ (1.17)	0.49 (2.01)	<.001
FCEC	$2.29_{2,3,4,5,6}$ (1.34)	$1.66_{1,3,4,5,6}$ (1.40)	$0.02_{1,2,4,5,6}$ (1.04)	$0,32_{1,2,3,5,6}$ (1,84)	$0.63_{1,2,3,4,6}$ (1.61)	$-2.91_{1,2,3,4,5}$ (1.68)	0.50 (1.89)	<.001
EBI	$2.49_{2,3,4,5,6}$ (1.38)	$1.61_{1,3,4,5,6}$ (1.53)	$0.41_{1,2,4,5,6}$ (1.38)	$0,18_{1,2,3,5,6}$ (2,10)	$1.19_{1,2,3,4,6}$ (1.86)	$-2.00_{1,2,3,4,5}$ (2.31)	0.78 (1.98)	<.001
ACWS	$2.10_{2,3,4,5,6}$ (1.50)	$1.60_{1,3,4,5,6}$ (1.38)	$0.14_{1,2,4,5,6}$ (1.05)	$-0,55_{1,2,3,5,6}$ (2,21)	$-1.13_{1,2,3,4,6}$ (1.82)	$-2.84_{1,2,3,4,5}$ (1.82)	0.26 (2.18)	<.001
ACNS	$1.66_{2,3,4,5,6}$ (1.82)	$0.86_{1,3,4,5,6}$ (1.94)	$-0.21_{1,2,4,5,6}$ (1.36)	$-1,94_{1,2,3,5,6}$ (2,07)	$-3.04_{1,2,3,4}$ (1.21)	$-3.28_{1,2,3,4}$ (1.51)	-0.60 (2.30)	<.001
ACPT	$2.07_{2,3,4,5,6}$ (1.56)	$1.11_{1,3,4,5,6}$ (1.61)	$0.03_{1,2,4,5,6}$ (1.23)	$-1,59_{1,2,3,5,6}$ (1,96)	$-1.93_{1,2,3,4,6}$ (1.76)	$-3.15_{1,2,3,4,5}$ (1.47)	-0.22 (2.14)	<.001
SCS	$1.85_{2,3,4,5,6}$ (1.45)	$0.31_{1,3,4,6}$ (1.58)	$-0.07_{1,2,4,5,6}$ (1,08)	$-2,14_{1,2,3,5,6}$ (1,57)	$0.15_{1,3,4,6}$ (1.72)	$-3.19_{1,2,3,4,5}$ (1.25)	-0.23 (1.90)	<.001
FCS	$2.09_{2,3,4,5,6}$ (1.31)	$0.58_{1,3,4,5,6}$ (1.49)	$0.05_{1,2,4,6}$ (0.98)	$-2,58_{1,2,3,5,6}$ (1,37)	$0.65_{1,3,4,6}$ (1.37)	$-3.16_{1,2,3,4,5}$ (1.33)	-0.09 (1.92)	<.001
PCS	$1.86_{2,3,4,5,6}$ (1.44)	$-0.03_{1,4,6}$ (1.62)	$-0.15_{1,4,5,6}$ (1.11)	$-2,91_{1,2,3,5,6}$ (1,17)	$0.14_{1,3,4,6}$ (1.54)	$-3.27_{1,2,3,4,5}$ (1.18)	-0.43 (1.94)	<.001
RS	$1.93_{2,3,4,5,6}$ (1.44)	$0.33_{1,3,4,6}$ (1.64)	$-0.06_{1,2,4,5,6}$ (1.09)	$-2,81_{1,2,3,5,6}$ (1,26)	$0.49_{1,3,4,6}$ (1.56)	$-3.25_{1,2,3,4,5}$ (1.25)	-0.25 (1.99)	<.001

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

ICE = Internal combustion engine car; PT = Public transport; BI = Bicycle; GF = Go on foot; HEC = Hybrid electric car; BEC = Battery electric car; FCEC = Fuel cell electric car; EBI= Electric bike; AVWS = Autonomous vehicle with steering wheel; AVNS = Autonomous vehicle with no steering wheel, AVPT = Autonomous vehicle for public transport, SCS = Station-based carsharing, FCS = Free-floating carsharing; PCS = Private carsharing, RS = Ride sharing

Table 2. Potency ratings of transport modes for each segments and total sample

	Cluster							
	1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)	Total Sample	*p*
Transport mode	**Potency**							

ICE	$1.97_{3,5}$ (1.64)	$1.90_{3,5}$ (1.44)	$0.93_{1,2,4,5,6}$ (1.47)	1.75_{3} (1.71)	1.70_{3} (1.56)	1.70_{3} (1.97)	1.50 (1.63)	<.001
PT	$1.61_{2,3,4,5,6}$ (1.60)	$-0.23_{1,3,4,6}$ (1.69)	$0.17_{1,2,4,5,6}$ (1.50)	$-1.02_{1,2,3,5}$ (1.94)	$-0.17_{1,3,4,6}$ (1.90)	$-1.06_{1,2,3,5}$ (2.31)	-0.05 (1.88)	<.001
BI[c]	$1.96_{2,3,4,5,6}$ (1.61)	$0.24_{1,4,5,6}$ (1.70)	$0.25_{1,4,5,6}$ (1.61)	$-0.10_{1,2,3,5}$ (2.03)	$0.71_{1,2,3,4,6}$ (1.84)	$-0.25_{1,2,3,5}$ (2.42)	0.41 (1.88)	<.001
OF	$1.94_{2,3,4,5,6}$ (1.73)	$0.13_{1,3,5}$ (1.91)	$0.56_{1,2,4,5}$ (1.65)	$0.14_{1,3,5}$ (2.11)	$0.80_{1,2,3,4,6}$ (1.97)	$0.36_{1,5}$ (.,38)	0.58 (1.95)	<.001
HEC	$2.20_{2,3,4,5,6}$ (1.39)	$1.38_{1,3,4,5,6}$ (1.30)	$-0.11_{1,2,4,5,6}$ (0.96)	$0.27_{1,2,3,5,6}$ (1.57)	$0.60_{1,2,3,4,6}$ (1.49)	$-3.05_{1,2,3,4,5}$ (1.40)	0.30 (1.79)	<.001
BEC	$2.14_{2,3,4,5,6}$ (1.39)	$1.09_{1,3,4,5,6}$ (1.46)	$-0.19_{1,2,5,6}$ (1.08)	$-0.10_{1,2,5,6}$ (1.86)	$0.22_{1,2,3,4,6}$ (1.65)	$-3.31_{1,2,3,4,5}$ (1.10)	0.15 (1.87)	<.001
FCEC	$2.13_{2,3,4,5,6}$ (1.34)	$1.30_{1,3,4,5,6}$ (1.35)	$-0.07_{1,2,4,5,6}$ (0.94)	$0.25_{1,2,3,6}$ (1.71)	$0.42_{1,2,3,6}$ (1.47)	$-2.96_{1,2,3,4,5}$ (1.62)	0.34 (1.78)	<.001
EBI	$2.21_{2,3,4,5,6}$ (1.45)	$0.86_{1,2,4,6}$ (1.52)	$0.17_{1,2,3,5,6}$ (1.21)	$-0.08_{1,3,4,5}$ (1.97)	$0.72_{1,2,3,4,5}$ (1.74)	-2.08 (2.17)	0.41 (1.84)	<.001
ACWS	$2.10_{2,3,4,5,6}$ (1.50)	$1.60_{1,3,4,5,6}$ (1.38)	$0.14_{1,2,4,5,6}$ (1.05)	$-0.55_{1,2,3,5,6}$ (2.21)	$-1.13_{1,2,3,4,6}$ (1.82)	$-2.84_{1,2,3,4,5}$ (1.82)	0.18 (2.03)	<.001
ACNS	$1.66_{2,3,4,5,6}$ (1.76)	$0.86_{1,3,4,5,6}$ (1.75)	$-0.06_{1,2,4,5,6}$ (1.15)	$-1.83_{1,2,3,5,6}$ (2.03)	$-2.78_{1,2,3,4,6}$ (1.43)	$-3.25_{1,2,3,4,5}$ (1.53)	-0.50 (2,20)	<.001
ACPT	$1.91_{2,3,4,5,6}$ (1.55)	$0.78_{1,3,4,5,6}$ (1.46)	$0.04_{1,2,4,5,6}$ (1.06)	$-1.55_{1,2,3,5,6}$ (1.88)	$-1.76_{1,2,3,4,6}$ (1.70)	$-3.11_{1,2,3,4,5}$ (1.46)	-0.60 (2.12)	<.001
SCS	$1.67_{2,3,4,5,6}$ (1.44)	$0.03_{1,3,4,6}$ (1.37)	$-0.12_{1,2,4,6}$ (0.91)	$-2.07_{1,2,3,5,6}$ (1.54)	$-0.12_{1,4,6}$ (1.56)	$-3.14_{1,2,3,4,5}$ (1.28)	-0,36 (1.75)	<.001
FCS	$1.89_{2,3,4,5,6}$ (1.29)	$0.23_{1,3,4,5,6}$ (1.21)	$-0.02_{1,2,4,5,6}$ (0.82)	$-2.48_{1,2,3,5,6}$ (1.33)	$0.46_{1,2,3,4,6}$ (1.19)	$-3.12_{1,2,3,4,5}$ (1.34)	-0.22 (1.76)	<.001
PCS	$1.72_{2,3,4,5,6}$ (1.41)	$-0.16_{1,4,5,6}$ (1.29)	$-0.15_{1,4,5,6}$ (0.92)	$-2.70_{1,2,3,5,6}$ (1.24)	$0.01_{1,2,3,4,6}$ (1.32)	$-3.22_{1,2,3,4,5}$ (1.20)	-0.47 (1.77)	<.001
RS	$1.73_{2,3,4,5,6}$ (1.43)	$-0.02_{1,4,5,6}$ (1.33)	$-0.11_{1,4,5,6}$ (0.90)	$-2.76_{1,2,3,5,6}$ (1.23)	$0.26_{1,2,3,4,6}$ (1.40)	$-3.22_{1,2,3,4,5}$ (1.24)	-0.39 (1.81)	<.001

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

ICE = Internal combustion engine car; PT = Public transport; BI = Bicycle; GF = Go on foot; HEC = Hybrid electric car; BEC = Battery electric car; FCEC = Fuel cell electric car; EBI= Electric bike; AVWS = Autonomous vehicle with steering wheel; AVNS = Autonomous vehicle with no steering wheel, AVPT = Autonomous vehicle for public transport, SCS = Station-based carsharing, FCS = Free-floating carsharing; PCS = Private carsharing, RS = Ride sharing

Table 3. Activity ratings of transport modes for each segments and total sample

	Cluster							
	1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)	Total Sample	*p*
Transport mode	**Activity**							
ICE	$1.94_{3,4,5,6}$ (1.55)	$1.86_{3,4,5}$ (1.43)	$0.88_{1,2,4,5,6}$ (1.39)	$1.60_{1,2,3}$ (1.65)	$1.58_{1,2,3}$ (1.52)	$1.63_{1,3}$ (1.90)	1.44 (1.57)	<.001

PT	$1.27_{2,3,4,5,6}$ (1.67)	$-0.38_{1,3,4,6}$ (1.56)	$0.08_{1,2,4,5,6}$ (1.40)	$-0.82_{1,2,3,5}$ (1.86)	$-0.24_{1,3,4,6}$ (1.69)	$-0.84_{1,2,3,5}$ (2.21)	-0.11 (1.73)	<.001
BI[c]	$1.62_{2,3,4,5,6}$ (1.73)	$-0.07_{1,3,4,5,6}$ (1.65)	$0.15_{1,2,4,6}$ (1.56)	$-0.35_{1,2,3,5}$ (1.90)	$0.16_{1,2,4,6}$ (1.81)	$-0.44_{1,2,3,5}$ (2.30)	0.16 (1.82)	<.001
OF	$0.75_{2,3,4,5,6}$ (2.26)	$-1.29_{1,3,4,5,6}$ (1.89)	$-0.20_{1,2,4,5}$ (1.82)	$-0.81_{1,2,3,6}$ (2.17)	$-0.82_{1,2,3,6}$ (2.03)	$-0.27_{1,2,4,5}$ (2.38)	-0.50 (2.09)	<.001
HEC	$2.05_{2,3,4,5,6}$ (1.43)	$1.04_{1,3,4,5,6}$ (1.35)	$-0.11_{1,2,4,5,6}$ (0.92)	$0.24_{1,2,3,6}$ (1.40)	$0.34_{1,2,3,6}$ (1.39)	$-2.84_{1,2,3,4,5}$ (1.55)	0.25 (1.69)	<.001
BEC	$2.00_{2,3,4,5,6}$ (1.44)	$0.72_{1,3,4,5,6}$ (1.50)	$-0.20_{1,2,5,6}$ (1.03)	$-0.11_{1,2,6}$ (1.69)	$0.02_{1,2,3,6}$ (1.55)	$-3.08_{1,2,3,4,5}$ (1.32)	0.04 (1.77)	<.001
FCEC	$2.01_{2,3,4,5,6}$ (1.35)	$1.03_{1,3,4,5,6}$ (1.39)	$-0.10_{1,2,4,5,6}$ (0.88)	$0.28_{1,2,3,6}$ (1.57)	$0.21_{1,2,3,6}$ (1.36)	$-2.73_{1,2,3,4,5}$ (1.72)	0.25 (1.68)	<.001
EBI	$2.01_{2,3,4,5,6}$ (1.46)	$0.57_{1,3,4,6}$ (1.56)	$0.11_{1,2,5,6}$ (1.18)	$-0.01_{1,2,5,6}$ (1.81)	$0.50_{1,3,4,6}$ (1.65)	$-2.03_{1,2,3,4,5}$ (2.16)	0.28 (1.76)	<.001
ACWS	$1.91_{2,3,4,5,6}$ (1.51)	$1.20_{1,3,4,5,6}$ (1.49)	$0.14_{1,2,4,5,6}$ (0.95)	$-0.39_{1,2,3,5,6}$ (2.01)	$-0.61_{1,2,3,4,6}$ (1.61)	$-2.55_{1,2,3,4,5}$ (1.95)	0.18 (1.84)	<.001
ACNS	$1.60_{2,3,4,5,6}$ (1.62)	$0.69_{1,3,4,5,6}$ (1.56)	$0.02_{1,2,4,5,6}$ (1.03)	$-1.28_{1,2,3,6}$ (1.98)	$-1.46_{1,2,3,6}$ (1.88)	$-2.87_{1,2,3,4,5}$ (1.79)	-0.24 (1.94)	<.001
ACPT	$1.68_{2,3,4,5,6}$ (1.54)	$0.53_{1,3,4,5,6}$ (1.39)	$0.06_{1,2,4,5,6}$ (0.95)	$-1.12_{1,2,3,6}$ (1.80)	$-0.98_{1,2,3,6}$ (1.68)	$-2.82_{1,2,3,4,5}$ (1.67)	-0.17 (1.78)	<.001
SCS	$1.53_{2,3,4,5,6}$ (1.40)	$0.02_{1,3,4,5,6}$ (1.22)	$-0.06_{1,4,6}$ (0.83)	$-1.65_{1,2,3,5,6}$ (1.66)	$-0.08_{1,4,6}$ (1.40)	$-2.84_{1,2,3,4,5}$ (1.53)	-0.28 (1.62)	<.001
FCS	$1.73_{2,3,4,5,6}$ (1.30)	$0.20_{1,3,4,5,6}$ (1.14)	$0.02_{1,2,4,5,6}$ (0.74)	$-2.06_{1,2,3,5,6}$ (1.53)	$0.41_{1,2,3,4,6}$ (1.07)	$-2.88_{1,2,3,4,5}$ (1.49)	-0.17 (1.64)	<.001
PCS	$1.65_{2,3,4,5,6}$ (1.33)	$-0.06_{1,4,5,6}$ (1.18)	$-0.05_{1,4,5,6}$ (0.83)	$-2.24_{1,2,3,5,6}$ (1.52)	$0.17_{1,2,3,4,6}$ (1.13)	$-2.97_{1,2,3,4,5}$ (1.40)	-0.32 (1.66)	<.001
RS	$1.64_{2,3,4,5,6}$ (1.39)	$0.08_{1,3,4,5,6}$ (1.20)	$-0.06_{1,2,4,5,6}$ (0.79)	$-2.26_{1,2,3,5,6}$ (1.52)	$0.31_{1,2,3,4,6}$ (1.22)	$-2.96_{1,2,3,4,5}$ (1.44)	-0.28 (1.68)	<.001

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

ICE = Internal combustion engine car; PT = Public transport; BI = Bicycle; GF = Go on foot; HEC = Hybrid electric car; BEC = Battery electric car; FCEC = Fuel cell electric car; EBI= Electric bike; AVWS = Autonomous vehicle with steering wheel; AVNS = Autonomous vehicle with no steering wheel, AVPT = Autonomous vehicle for public transport, SCS = Station-based carsharing, FCS = Free-floating carsharing; PCS = Private carsharing, RS = Ride sharing

Affective meanings of segments about transport modes

To identify the differences between input variables of cluster analysis across segments we conducted a MANOVA with Tukey's post-hoc test. Table 1.1 – 1.3 presents mean values of affective meanings used in the segmentation analysis. As would be expected, all six clusters differed significantly on the input variables (F = (225,29350) = 113.64, $p \leq .001$; Wilk's λ = .044, partial η^2 = .47), in particular in EPA ratings about innovative transport concepts. Here, we summarize the EPA affective meaning profiles of each cluster included in the cluster analysis in brief.

Eco-oriented opinion leaders (Cluster 1) evaluated among traditional transport modes traveling on foot and by bicycle as most positive (*E*), by public transport as least powerful (*P*) and by internal combustion engine (ICE) car as most exciting/ fastest (*A*). They are the segment with the most positive affective representations towards all sustainable transport innovations. Among these, electric bikes (EBI) were perceived as the most positive and powerful and hybrid electric cars (HEC) as most exciting/ fastest new transport concept. In the domain of self-driving vehicles affective meanings of autonomous cars with steering wheel (ACWS) and for public transport (ACPT) were positive, whereas ACWS were also seen as most powerful and exciting. Among the four different carsharing concepts (i.e., station-based carsharing, free-floating carsharing, private carsharing, and ride sharing) free-floating carsharing (FCS) was seen as most positive, powerful, and exciting/fast.

For *Innovation-oriented progressives* (Cluster 2) walking on foot (OF) was the most positive, and ICE car the most powerful and exciting/fastest traditional transport mode. Public transport (PT) received the lowest rating on the dimensions evaluation and potency, and OF was seen as the calmest/slowest travel mode. Affective meanings of sustainable transport innovations were in general positive in this group, but with considerable variation across domains. HEC were viewed as most positive and ACWS as most powerful and exciting/fastest. Affective ratings of carsharing concepts were on a significantly lower level than electric and autonomous vehicles. In particular, private carsharing (PCS) was perceived somewhat negatively.

Members of the group *Cost-conscious pragmatics* (Cluster 3) showed the most positive evaluation of walking and viewed ICE cars as the most powerful and exciting/fastest traditional mode of transport. Among these modes, PT was seen as the least positive and powerful, and walking as slowest. Interestingly, this segment perceived all novel transport concepts mostly as emotionally neutral. Among these, electric bikes (EB) did elicit the most positive feelings and were seen as somewhat powerful and exciting/fast. Among self-driving vehicles, autonomous cars with no steering wheel (ACNS) and among carsharing concepts private carsharing (PCS) were seen most negatively.

Comfort-oriented individualists (Cluster 4) expressed the most positive feelings for ICE cars across all three dimensions, whereas PT consistently elicited among traditional transport modes feelings on the negative side of the spectrum. Their affective representations of transport innovations reflect skepticism in particular about autonomous vehicles (AVs) and carsharing concepts. They viewed hybrid electric and fuel cell electric cars at a comparable level as somewhat positive, powerful, and exciting/fast. In contrast, among AVs autonomous cars with no steering wheel (ACNS) were seen as most negative along the three EPA dimensions. Their emotional reluctance was even more pronounced towards private carsharing and ride sharing, both seen as very negative, powerless and calm/slow.

Common good-oriented city dwellers (Cluster 5) viewed walking as the most positive traditional mode of travel, and ICE car as most powerful and exciting/fast. PT was represented as emotionally neutral. The affective meanings of sustainable transport innovations elicited support for electric vehicles and carsharing. Electric bikes (EBI) were seen as the most positive, powerful, and exciting/fastest type of EVs. Among the four different forms of carsharing, free-floating systems were consistently evaluated most positively. Autonomous cars with no steering wheel were seen as most negative, powerless, and least exciting.

Risk-averse traditionalist (Cluster 6*)* favored mostly ICE cars. Among traditional transport modes, PT elicited the most negative emotions. Moreover, members of this segment perceived traveling on foot and by bicycle more negatively than all the other groups. Their feelings about transport innovations are on the opposite end of the spectrum compared to *Eco-oriented opinion leaders.* Their emotional reluctance to new forms of traveling is consistently high across all domains. Among these, full battery electric, autonomous cars with no steering wheel, ridesharing, and private carsharing were seen as most negative, powerless and at least exciting.

Socio-demographic, personal and attitudinal characteristics of segments

The segments differed significantly in various socio-demographic, personal and attitudinal characteristics – variables that were not included in the cluster analysis. An overview of socio-demographics of each cluster and the total sample is provided in Table 2. Additional profiling information regarding cognitive attitudes, individual relevance of transport mode attributes, party identification, values, subjective innovativeness and opinion leadership, tendency of risk-taking and life satisfaction of segments can be found in Appendix A in Table A1 – A5.2. The following description summarizes the individual characteristics and basis of the labels of each segment.

Table 4. Sociodemographic characteristics of each segment and of the total sample

		Cluster						
		1 (EL) (n = 617, 10.4%)	2 (IP) (n = 1298, 21.8%)	3 (CP) (n = 2088, 35.1%)	4 (CI) (n = 672, 11.3%)	5 (CD) (n = 810, 13.6%)	6 (RT) (n = 463, 7.8%)	Total Sample (N = 5948, 100%)
Gender**	Female	47.5%	44.0%	55.1%	40.2%	59.5%	54.4%	50.8%
Age (in years)**	16-29	29.2%	30.8%	26.5%	13.7%	21.3%	9.5%	24.2%
	30-39	15.6%	14.0	13.7%	13.4%	11.0%	10.8%	13.3%
	40-49	19.1%	16.8	21.4%	22.0%	19.5%	22.2%	20.0%
	50-59	21.6%	22.9	21.9%	28.3%	28.3%	30.7%	24.3%
	>60	14.6%	15.5	16.5%	22.6%	20.0%	26.8%	18.1%
Education**	Secondary school	22.4%	19.3%	32.3%	31.1%	26.2%	35.0%	27.7%
	Intermediate secondary school	30.3%	35.4%	33.6%	34.5%	34.9%	40.8%	34.5%
	Grammar school	45.4%	43.7%	31.8%	33.0%	37.5%	21.4%	35.9%
	University degree	29.8%	22.1%	16.1%	17.6%	19.6%	11.4%	19.1%
Income**	Less than 900€ / month	7.1%	7.4%	10.2%	4.8%	8.3%	8.6%	8.3%
	900€ - 1500€ / month	19.9%	14.3%	20.3%	15.3%	19.8%	21.4%	18.4%
	1501€ - 2000€/ month	13.5%	14.3%	16.7%	14.6%	14.4%	14.9%	15.1%
	2001€ - 2600€/ month	15.7%	16.3%	16.2%	17.0%	14.1%	15.8%	15.9%
	2601€ - 3600€/ month	20.6%	18.2%	16.7%	18.0%	19.6%	19.4%	18.2%
	3601€ - 5000€/ month	13.9%	17.2%	12.8%	15.6%	15.2%	13.8%	14.6%
	More than 5000€ / month	9.2%	12.3%	7.1%	14.7%	8.6%	6.0%	9.4%
Number of children in the household**	0	67.9%	74.0%	71.7%	76.6%	76.9%	80.8%	73.8%
	1	16.9%	15.8%	17.3%	13.9%	13.7%	10.7%	15.5%
	2	11.1%	8.0%	8.4%	6.4%	7.2%	6.1%	8.0%
	3	2.6%	1.6%	1.9%	2.1%	1.9%	1.3%	1.9%
	≥4	1.5%	=0.7%	0.7%	0.9%	0.3%	1.1%	0.8%
Residential Area**	Cities > 500.000 inh.	25.3%	20.9%	21.1%	16.4%	23.6%	16.8%	23.0%
	Cities 100.000 - 500.000 inh.	19.8%	14.7%	17.9%	16.1%	14.8%	13.5%	13.1%
	Cities 50.000 - 99.999 inh.	11.8%	9.4%	8.7%	10.1%	11.2%	10.3%	16.7%
	Cities 20.000 - 49.999 inh.	14.0%	17.4%	16.1%	16.3%	17.4%	20.6%	9.8%
	Small cities 10.000 – 19.999 inh.	10.8%	14.3%	12.2%	16.1%	12.9%	13.0%	16.4%
	Villages <9.999 inh.	18.4%	23.3%	24.0%	25.1%	20.1%	25.8%	21.0%
Duration of residence at current address in years ** (Mean/SD)		18.20 (16.62)	19.93 (16.41)	20.20 (17.51)	23.16 (22.25)	22.67 (18.33)	21.10 (18.30)	20.59 (17.60)

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*
** $p < .01$

Eco-oriented opinion leaders indicated the highest importance across segments for the attribute environmental friendliness when choosing a transport mode and were most likely to consider themselves as opinion leaders. This group was the second youngest, mainly aged between 16-29 years and most likely to be male. They indicated a high level of education and residency in large cities (> 500.000 inhabitants), where their duration of residency at the current place of living was the shortest among all segments. The number of children living in the household was the highest among all segments. Members of this group stood out in the personal importance of all value types according to the Schwartz value circle (Shalom H. Schwartz, 2012), except for self-direction, and contained the highest proportion of voters politically affiliated with the Green Party (Bündnis 90/ Die Grünen), the Left-wing Party (die Linke) and the Social Democratic Party (SPD). They reported the highest levels of innovativeness, tendency of risk-taking, and life satisfaction among segments. They believe that traveling on foot and by bicycle best facilitates their personal needs (i.e., attributes of mode choice) of daily travel activities.

Innovation-oriented progressives scored highest on the personal innovativeness scale and showed an overall high level of adoption intention towards travel innovations. They were the youngest segment, containing the highest proportion of 16-29 years-olds. Members of this group were more likely to be male, to reside in smaller cities, and to have an above average level of education. They scored above average on the personal value dimension openness-to-change, and were most likely to vote for the Conservatives (CDU/CSU), Social Democratic Party (SPD), or the Greens (Bündnis 90/ Die Grünen). Their levels of self-reported opinion leadership, risk-taking, and life satisfaction were second-highest among clusters. They believe that ICE cars meet their daily travel needs best among traditional transport modes.

Cost-conscious pragmatics reported the lowest household income. The relevance of non-instrumental attributes of transport modes such as independence, comfort, driving experience was below that of other clusters. They were more likely to be female, and the number of children in the household was the second-highest among segments. Their mean age and their level of education was below the sample average and comprised the highest proportion of undecided voters. They exhibit low levels on innovativeness, opinion leadership, and tendency of risk-taking. Their life satisfaction is the lowest of all clusters. Cognitive attitudes of this segment entail a preference for walking and ICE cars for their daily travel activities.

For *Comfort-oriented individualists,* comfort and independence/flexibility of transport modes were more important than for other segments. They comprised the highest proportion of males, were mainly aged between 50-59 years, and most likely to live in smaller towns and villages. Their household income was the highest across segments, whereas their educational level was below average. This segment scored low on the personal value dimensions openness-to-change and self-transcendence. Accordingly, they identified mainly with conservative political parties. Their ratings on innovativeness, opinion leadership, and risk-taking tendency were below average. Members of this segment showed the most positive cognitive attitudes towards ICE cars among all segments.

Common good-oriented city dwellers indicated high importance of the values universalism and benevolence and comprised the second-highest proportion of people living in big cities. They comprised the highest proportion of females, were older than the sample mean and tended to have a high level of education. This segment was most likely to identify with the Conservatives (CDU/ CSU), the Social Democratic Party (SPD), or the Green Party (Bündnis 90/ Die Grünen). They scored above average on innovativeness and opinion leadership, but their tendency of risk-taking and life satisfaction were on the same level as the average of the sample. They believe that ICE cars and walking best meet their daily travel needs.

Risk-averse traditionalists' attitudinal and socio-demographic profiles were mostly opposite to the group of *Eco-oriented opinion leaders.* They scored lowest on risk-taking and innovativeness. This group was the oldest of all segments. They were likely to be female, to reside in midsize cities and to have no children in the household, at a slightly-below-average income level. The mean duration of residence at their current place of living was the highest among all clusters. They mainly identify with conservative parties and comprised the highest proportion of people affiliated with the nationalistic protest party Alternative for Germany (AfD). Their beliefs about traditional transport modes indicate most clearly their strong preference for ICE cars.

Travel behaviour and innovation-adoption intentions

Finally, we examined how variations in affective meanings across segments correspond to respondents' current daily travel behaviour and to their willingness to adopt more sustainable transport modes in the future. Table 3 shows various self-reported indicators of travel behaviour concerning traditional transport modes. Results revealed a specific pattern of behaviours of each group, fairly consistent with their affective-meaning profiles. For instance, segments which evaluated ICE cars most positive, i.e. *Comfort-oriented individualists* and *Risk-averse traditionalist*, comprised the highest share of respondents actually using ICE cars and the lowest using PT as their main mode of travel. *Comfort-oriented individualists,* in particular, stood out as the most car-dependent group, as indicated by its highest levels of cars per household, driving license holders, and annual car mileage. In contrast, groups with most positive representations of sustainable modes of transportation tended to use corresponding travel modes, e.g. bicycles, PT, and walking. Thus, *Eco-oriented opinion leaders* had the highest rate of respondents that reported bicycling and PT as their main mode of transportation. *Cost-conscious pragmatics* were most likely to report walking as their main mode. Conversely, both groups reported the lowest levels of cars per household and of driving-license holders. Also, the rate of respondents indicating that they never use cars was highest among all segments. Interestingly, *Common good-oriented city dwellers* and *Eco-oriented opinion leaders* comprised the highest share of persons reporting moral obligation as the reason for not using ICE cars anymore.

Table 5. Indicators of travel behavior for each segment and the total sample

		Cluster						
		1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)	Total sample
Cars per household**	No	20.1%	10.7%	21.8%	8.6%	17.0%	15.3%	16.6%
	1	49.9%	48.7%	46.2%	50.3%	48.3%	52.9%	48.4%
	2	25.1%	30.4%	25.3%	33.3%	26.7%	23.5%	27.4%
	≥3	4.9%	10.2%	6.7%	7.7%	8.0%	8.2%	7.7%
Driving license (yes)**		82.8%	88.9%	81.3%	91.4%	89.4%	87.0%	85.8%
Main mode	ICE Car**	37.3%	50.2%	43.4%	62.9%	47.4%	61.8%	48.5%
	Public transport**	16.2%	9.9%	14.2%	7.3%	12.5%	8.9%	12.1%
	Bicycle*	15.6%	11.4%	11.0%	6.5%	11.5%	7.6%	10.8%
	Walking	26.9%	23.8%	28.2%	18.5%	25.7%	17.7%	24.8%
	Carsharing**	0.5%	0.3%	0.0%	0.0%	0.0%	0.2%	0.1%
Annual car mileage**	No car use	19.6%	11.2%	23.2%	10.4%	14.9%	15.6%	17.0%
	Less than 5000 km /year	17.0%	18.6%	17.8%	12.8%	17.0%	16.6%	17.1%
	5001 – 10000 km /year	16.5%	20.2%	19.3%	21.1%	21.4%	22.5%	19.9%
	10001 – 15000 km /year	13.0%	18.6%	15.8%	19.8%	16.8%	16.2%	16.7%
	15001 – 20000 km /year	19.6%	16.6%	12.6%	15.6%	16.9%	14.3%	15.3%
	> 20000 km/year	14.4%	14.9%	11.4%	20.5%	13.0%	14.9%	14.0%
Reasons not to use Cars*	No need	24.0%	20.7%	30.9%	25.7%	20.7%	26.4%	26.7%
	Moral obligation	15.7%	8.3%	11.8%	12.9%	17.4%	6.9%	12.1%
	For financial reasons	26.4%	28.3%	28.2%	32.9%	33.9%	33.3%	29.4%
	For health reasons	7.4%	10.3%	7.2%	4.3%	5.8%	6.9%	7.3%
	For age reasons	5.0%	3.4%	4.3%	8.6%	5.8%	4.2%	4.7%
	Other reasons	20.7%	29.0%	17.5%	15.7%	16.5%	22.2%	19.6%
Ticket for PT**	Never use PT[a]	14.6%	21.6%	24.5%	37.2%	20.0%	42.3%	25.0%
	Single ticket	45.5%	50.8%	44.9%	44.5%	51.6%	40.2%	46.7%
	Weekly/monthly ticket	10.2%	5.6%	6.3%	4.0%	7.4%	2.6%	6.2%
	Annual ticket	19.9%	11.9%	14.7%	8.9%	11.9%	11.9%	13.4%
	Job/student ticket	9.7%	10.2%	9.6%	5.4%	9.1%	3.0%	8.7%
Use of smartphone app for** … (≥ 1-3 day/ week)	… renting PB**	5.9%	0.9%	1.5%	0.5%	1.4%	1.7%	1%
	… ordering Taxi**	7.1%	1.0%	2.0%	4.3%	0.7%	1.4%	1.6%
	… renting carsharing car**	7.1%	0.9%	1.4%	0.3%	2.0%	0.8%	1.4%
	… for intermodal travel**	10.5%	3.5%	3.3%	2.1%	2.4%	1.7%	3.3%

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*
ICE = Internal combustion engine car; PT = Public transport; PB = Public bicycle
* $p < .05$; ** $p < .01$

MANOVA results also revealed substantial differences on adoption intention of novel transport options between clusters (F (45, 26547) = 110.5, $p \leq .001$; Wilk's $\lambda = .464$, partial $\eta^2 = .14$). Mean values of adoption intentions towards nine innovations are presented in Table 4. The patterns of intended behaviours across clusters were again in line with their specific characteristics as described above. Overall, *Eco-oriented opinion leaders* and *Innovation-oriented progressives* showed the highest willingness to adopt transport innovations. Whereas the first group indicated strongest preferences for carsharing concepts, in particular for private carsharing, the stated intentions in the second group were highest for the use of autonomous and electric vehicles. Members of the *Common good-oriented city dwellers* segment demonstrated nuanced adoption tendencies. They moderately preferred carsharing concepts and electric bikes, but expressed low interest in using autonomous cars. The other three segments expressed in parts markedly low interest in travel innovations. *Risk-averse traditionalists were* least likely to adopt electric cars, *Comfort-oriented individualists* to use carsharing, and for members of the *Cost-conscious pragmatics* group, electric cars were their least preferred innovation.

Table 6. Adoption intention of various sustainable transport innovations of each segment

		Cluster						
		1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)	
		Mean z-values	Mean z-values	Mean z-values	Mean z-values	Mean z-values	Mean z-values	*p*
Intention to adopt	EV	$0.77_{2,3,4,5,6}$	$0.50_{1,3,4,5,6}$	$-0.29_{1,2,4,5,6}$	$-0.11_{1,2,3,6}$	$-0.06_{1,2,3,6}$	$-0.86_{1,2,3,4,5}$	<.001
	EBI	$0.73_{2,3,4,5,6}$	$0.23_{1,3,4,5,6}$	$-0.19_{1,2,5,6}$	$-0.17_{1,2,5,6}$	$0.03_{1,2,3,4,6}$	$-0.58_{1,2,3,4,5}$	<.001
	AVWS	$0.75_{2,3,4,5,6}$	$0.59_{1,3,4,5,6}$	$-0.19_{1,2,5,6}$	$-0.18_{1,2,5,6}$	$-0.47_{1,2,3,4,6}$	$-0.71_{1,2,3,4,5}$	<.001
	AVNS	$0.83_{2,3,4,5,6}$	$0.49_{1,3,4,5,6}$	$-0.10_{1,2,4,5,6}$	$-0.29_{1,2,3,5,6}$	$-0.57_{1,2,3,4}$	$-0.58_{1,2,3,4}$	<.001
	AVPT	$0.89_{2,3,4,5,6}$	$0.51_{1,3,4,5,6}$	$-0.11_{1,2,4,5,6}$	$-0.40_{1,2,3,6}$	$-0.45_{1,2,3,6}$	$-0.74_{1,2,3,4,5}$	<.001
	SCS	$0.99_{2,3,4,5,6}$	$0.13_{1,3,4,6}$	$-0.09_{1,2,4,5,6}$	$-0.82_{1,2,3,4}$	$0.05_{1,3,4,6}$	$-0.49_{1,2,3,5}$	<.001
	FCS	$0.97_{2,3,4,5,6}$	$0.17_{1,3,4,6}$	$-0.11_{1,2,4,5,6}$	$-0.55_{1,3,4,6}$	$0.09_{1,3,4,6}$	$-0.63_{1,2,3,5}$	<.001
	PCS	$1.08_{2,3,4,5,6}$	$0.10_{1,3,4,5,6}$	$-0.06_{1,2,4,6}$	$-0.55_{1,2,4,6}$	$-0.01_{1,2,4,6}$	$-0.61_{1,2,3,5}$	<.001
	RS	$0.93_{2,3,4,5,6}$	$0.23_{1,3,4,6}$	$-0.12_{1,2,3,4,6}$	$-0.66_{1,2,3,5}$	$0.19_{1,3,4,6}$	$-0.73_{1,2,3,5}$	<.001

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

EV = Electric vehicle (battery, hybrid and fuel cell); EBI= Electric bike; AVWS = Autonomous vehicle with steering wheel; AVNS = Autonomous vehicle with no steering wheel, AVPT = Autonomous vehicle for public transport, SCS = Station-based carsharing, FCS = Free-floating carsharing; PCS = Private carsharing, RS = Ride sharing

Note: Numbers in subscript indicate which variable means of clusters differ significantly (MANOVA post hoc analysis (Tukey test); $p < 0.05$). For example, the superscript number $_2$ in the first cell indicates that cluster 1 differs significantly from cluster 2 in terms of their its intention to adopt EVs.

Discussion

´In this study, we examined affective meanings, beliefs, and intentional behaviours of the German population towards the use of various traditional and novel sustainable transport options. We proposed a theory-based segmentation model that uses variations of cultural affective meanings of transport modes to profile subgroups in the German population differently engaged in the transition to sustainable mobility. In the discussion that follows we consider the theoretical, methodological and the practical implications of our findings and make suggestions for future research.

Theoretical and methodological implications

This study is the first, to our knowledge, to characterize affective meanings of a broad range of transport mode options in society. While most other studies investigating symbolic and affective representations associated with modes of transportation focused on specific technologies (e.g. Bergstad et al., 2011), the present study included a comprehensive set of existing and upcoming transport mode options based on a quasi-representative sample of the German population. The results provide detailed information about the consensus and variations in affective representation of concepts related to transport within the population. Overall, we found that cultural affective meanings were more consensual for traditional than for novel travel modes. The highest consensus was found for internal combustion engine (ICE) cars as the most positive, powerful and exciting transport mode in the sample, indicating a culturally deeply rooted positive, powerful and active meaning of traditional cars. These findings confirm results from previous research that have shown that symbolism of cars does not vary as strongly across traveller segments as the symbolic meanings of EVs (see Anable et al., 2016). The stronger affective polarization towards new technologies and services, most pronounced for autonomous vehicles, can be explained in part by idiosyncratic differences in coping with uncertainty inherent in innovations (Midgley & Dowling, 1993; Morton et al., 2016; Sven, Patrick, & Martin, 2017). Indeed, we found that respondents with high degree of innovativeness and risk-taking tend to show more positive emotional reactions to innovation than participants with opposing characteristics. From a cultural point of view, recent work suggests that observed variations in affective meanings represent subcultural differences of affective meanings in society (Ambrasat et al., 2014). These disparities are shaped and reinforced through interpersonal communication within like-minded peer networks, leading to higher subcultural consensus within and an amplification of polarization across communities (Liu & Srivastava, 2015; Rogers, 2013; Salathé & Khandelwal, 2011). Further, in the case of novel transport options, the lack of factual information and personal experiences has been suggested to strengthen group-related affective and cultural predispositions (Binder, Cacciatore, Scheufele, Shaw, & Corley, 2012; D. M. Kahan, Braman, Gastil, Slovic, & Mertz, 2007).

The six identified segments varied substantially, corresponding with their group-specific affective-meaning patterns of travel modes, in terms of their travel behaviours, intentions to adopt new modes of transport, and personal characteristics. Our results corroborate the findings of earlier work emphasizing the linkage of non-instrumental factors, such as affective and symbolic meaning associated with specific action options in transport (e.g. Axsen & Kurani, 2012; Schuitema et al., 2013) as well as emotional responses to more general climate change threats (Susie Wang, Leviston, Hurlstone, Lawrence, & Walker, 2018), with intended and actual behaviours. In contrast to earlier studies, considering emotions of individuals as affective prompts for actions (e.g. Keller et al., 2012; Leviston & Walker, 2012; Myers, Nisbet, Maibach, & Leiserowitz, 2012) and using such event related emotional reactions as profiling variables for segmentation (e.g. Fernando, Kashima, & Laham, 2014; Hine et al., 2013) our study proposes an alternative approach of cultural symbolic meanings derived from affect control theory (Heise, 2007) to explain varying behavioural tendencies of subgroups in society. According to this theory, people strive to adopt behaviours that verify stable cultural affective meanings of identities and objects, which they share with their social communities. Theoretically, our domain-independent segmentation approach answers recent calls for a better understanding of how tailored information campaigns could account for the cultural diversity in society and the effects of culture on peoples' decisions (Caldas et al., 2015; Kahan, 2010). Future research should investigate whether the segmentation model based on the presented approach is more effective to understand motivational drivers of behaviour and to develop tailored strategies to encourage population behaviour change than existing methods using attitudinal, behavioural, or lifestyle data (e.g. Hine et al., 2013; Sütterlin, Brunner, & Siegrist, 2011; Walker & Li, 2007).

Considering the diversity of socially and culturally determined contexts of travel behaviors, the generalizability of our findings to other countries is limited. Haustein and Nielsen (2016), for example, revealed in a recent Europe-wide segmentation study substantial variations in mobility styles across nations. Moreover, past research on cross-cultural similarities of affective meanings in other behavioral domains identified meaningful differences between cultures (Schroder, Rogers, Ike, Mell, & Scholl, 2013). Hence, affective meanings and traveler segments may vary in other countries substantially from those identified in our study. However, our approach can be used to reconsider conceptualizations of consumer segmentations and to chart the apparent differences in transport behaviors and culturally specific barriers of a more sustainable transport system.

Following the theoretical framework of Heise (2007), we demonstrated that implicit cultural knowledge embedded in the affective meanings of verbal concepts can be used to identify segments in society with meaningful differences in characteristics relevant for the development of targeted measures aimed to promote behaviour change in the domain of transport. Our results show that measuring sentiments of concepts along the three cross-culturally universal dimensions evaluation, potency, and activity, provide a parsimonious, yet powerful way to assess cultural meanings of variables used in segmentation studies. The universality of affective dimensions facilitates cross-cultural segmentation studies and allows intra- as well as inter-culture comparisons of the respective behavioural domains. Moreover, the approach can be applied to segmentation models focusing on a single issue, like the current study, or approaches comprising multiple attitudinal or behavioural domains (e.g. Poortinga & Darnton, 2016). Ambrasat (2017), for example, showed in a recent study that affective representations of political parties can be used to identify segments with different partisan identification predictive in their voting behaviour patterns.

Practical implications and future directions

Psychographic segmentation models in general claim two central goals or benefits: (1) to provide a better understanding of the motivational factors underlying behaviours of different groups in the general public and (2) to enable practitioners and policy makers to develop tailored interventions and communications strategies to promote behaviour change that match the specific characteristics of segments (Lin, 2002; Smith, 1956). In practice, however, is often difficult to derive targeted strategies by using the segmentation solution because the transfer of provided information of segment profiles into specific messages and interventions remains unclear (cf. Hine et al., 2014) and the segment affiliations of individuals in a given community are not identifiable without additional research efforts. The segmentation approach presented here contributes to solving these problems in the following ways:

In line with previous empirical work (D. M. Kahan, Jenkins-Smith, & Braman, 2011; D. M. Kahan et al., 2012), our results suggest the development of communication strategies that uphold the group-specific cultural meanings of behaviours and innovations, to encourage an open-minded consideration of more sustainable mobility options. The language-based conceptualization and quantitative metric of cultural meanings provides therefore an estimate to what extent presented information is consistent with the respective affective meanings of mentioned concepts in subgroups. For instance, campaigns emphasizing the environmental benefits of public transport use (PT) are inconsistent with existing affective meanings, i.e. as an unpleasant (E), low status (P) and slow transport mode, of almost all groups - in particular of members of the *Comfort-oriented individualists and the Risk-averse Traditionalists segments*. Consequently, consumers will tend to ignore and reject this information. More effective are tailored social marketing campaigns promoting the use of alternative, more sustainable, transport modes that are positively connoted within their communities, i.e. for *Eco-oriented Opinion Leader* commuting on foot, by bicycle, electric bike or battery electric cars; for *Innovation-oriented progressives* traveling by electric cars (hybrid, full battery electric and fuel cell) or on foot; for *Cost-conscious pragmatics* traveling on foot, by bicycle or electric bike; for *Comfort-oriented individualists* walking, cycling, driving with hybrid electric or fuel cell cars; for *Common good-oriented city dwellers* commuting on foot, by bicycle, electric bike or car and by flexible carsharing; and finally for *Risk-averse Traditionalists* commuting on foot and by bicycle.

Recent studies have demonstrated that the effectiveness of persuasive appeals in online community platforms can be improved on a large scale when they are tailored to the psychological characteristics of targeted audiences (e.g. Matz, Kosinski, Nave, & Stillwell, 2017). To identify peoples' psychological profiles, these approaches require personal information of users such as self-reported socio-demographic and psychometric properties and/or explicit attitudinal expression (e.g. Facebook likes) (e.g. Kosinski, Stillwell, & Graepel, 2013). In practice, however, such data might not be available and may rise serious privacy concerns. Alternatively, advances in natural language processing and their successful application in the extraction of affective meanings and attitudes in online communication (e.g. Ahothali & Hoey, 2015) provide a promising avenue to adopt our approach for the identification of audience segments using machine learning techniques, for example in social media communities. Moreover, future work could apply and extend this approach to evaluate the effects of targeted campaigns aimed to change transport behaviour in real-word settings.

The results reported in this study referred to a nationwide sample of the German population. In practice, however, tailored and locally focused interventions and communication strategies often require a geographically more fine-grained understanding of the local composition of segments as well as their attitudinal and behavioural differences across regions. For this purpose, we created an interactive website comprising in more detail, the results of our study, which can be accessed free at https://monforsense-results.fh-potsdam.de. The results can be explored in georeferenced manner down to the state level as well as categorized by behavioural, socio- and psychographic dimension. Additionally, we provide on this website an agent-based modeling (ABM) framework, called InnoMind (*Inno*vation diffusion driven by changing *Minds*) to explore potential effects of specific policies and communications strategies targeting the identified segments of our study. This supplementary information enables policy makers to gain deeper insights into the local conditions and specific cultural characteristics of the population in a given region and might support the develop of tailored, and thus more effective targeted solutions and policies for sustainable transport.

Conclusion

Governing the transition to low-carbon mobility requires a comprehensive understanding of how culturally grounded meanings affect peoples' decision-making and behaviours. We demonstrated that variations in cultural affective meanings of transport modes across subgroups of the German population have an important role to play in their current travel behaviour and the willingness to adopt alternative transport options. These results provide insights into how members of the different segments interpret events and respond to relevant information, i.e. in a way that affirms the sentiment patterns they share with their social communities. This has important implications for the development of targeted persuasive appeals and behaviour change interventions promoting the adoption of more sustainable modes of transport. Future research should test whether communication strategies tailored to the specific affective meaning patters of different communities may enhance the effectiveness of interventions. Moreover, community-based social marketing may help to invest the concepts of transport with the kind of affective and symbolic meanings that are both agreeable with existing set of meanings shared within community and encourage the use of sustainable transport modes. Clearly, the biggest challenge remains the deeply culturally embedded representation of traditional cars as positive, powerful, and exciting, which requires the full range of policy options to achieve the decarbonization of the transport sector.

Acknowledgements

This research was funded by the German Federal Ministry for Education and Research (BMBF) (#16I1660 and #16I1659). We would like to thank Alice Bobée and Christian Mosau for their assistance in data collection and Nikolas Zoeller for helpful discussion.

Appendix A

See Tables A1–A5.2.

Table A1: Cognitive attitudes towards traditional and sustainable travel options of each segment

		Cluster					
		1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Cognitive attitudes towards…	ICE**	4.56$_{3}$ (0.89)	4.45$_{3}$ (0.66)	4.18$_{1,2,4,5,6}$ (0.94)	4.48$_{3}$ (0.81)	4.43$_{3}$ (0.79)	4.46$_{3}$ (1.11)
	PT**	4.20$_{2,3,4,5,6}$ (1.00)	3.36$_{1,4,6}$ (0.89)	3.45$_{1,4,6}$ (0.98)	2.93$_{1,2,3,5}$ (1.09)	3.38$_{1,4,6}$ (0.98)	2.86$_{1,2,3,5}$ (1.37)
	BI**	4.77$_{2,3,4,5,6}$ (0.88)	4.20$_{1,3,4,6}$ (0.86)	3.94$_{1,2,4,5,6}$ (1.12)	3.77$_{1,2,3,5,6}$ (1.12)	4.23$_{1,3,4,6}$ (0.96)	3.45$_{1,2,3,4,5}$ (1.42)
	GF**	4.78$_{2,3,4,5,6}$ (0.77)	4.31$_{1,4,6}$ (0.73)	4.23$_{1,4,5,6}$ (0.86)	4.06$_{1,2,3,5}$ (0.91)	4.42$_{1,3,4,6}$ (0.80)	3.98$_{1,2,3,6}$ (1.14)
	EV**	4.57$_{2,3,4,5,6}$ (0.88)	4.28$_{1,3,4,5,6}$ (0.76)	3.27$_{1,2,4,5,6}$ (1.08)	3.49$_{1,2,3,5,6}$ (1.08)	3.72$_{1,2,3,4,6}$ (1.02)	1.96$_{1,2,3,4,5}$ (1.07)
	EB**	4.47$_{2,3,4,5,6}$ (0.94)	3.,87$_{1,3,4,5,6}$ (0.85)	3.23$_{1,2,5,6}$ (1.10)	3.22$_{1,2,5,6}$ (1.12)	3.66$_{1,2,3,4,6}$ (1.01)	2.24$_{1,2,3,4,5}$ (1.26)
	AVWS**	4.30$_{2,3,4,5,6}$ (1.00)	4.01$_{1,3,4,5,6}$ (0.87)	3.04$_{1,2,5,6}$ (1.10)	2.92$_{1,2,5,6}$ (1.25)	2.74$_{1,2,3,4,6}$ (1.04)	1.73$_{1,2,3,4,5}$ (1.04)
	AVNS**	4.06$_{2,3,4,5,6}$ (1.13)	3.70$_{1,3,4,5,6}$ (0.90)	2.85$_{1,2,4,5,6}$ (1.10)	2.52$_{1,2,3,5,6}$ (1.14)	2.26$_{1,2,3,4,6}$ (0.92)	1.66$_{1,2,3,4,5}$ (1.01)
	AVPT**	4.15$_{2,3,4,5,6}$ (1.07)	3.63$_{1,3,4,5,6}$ (0.87)	2.92$_{1,2,4,5,6}$ (1.08)	2.47$_{1,2,3,6}$ (1.08)	2.52$_{1,2,3,6}$ (0.99)	1.65$_{1,2,3,4,5}$ (0.96)
	SCS**	4.10$_{2,3,4,5,6}$ (1.02)	3.37$_{1,3,4,5,6}$ (0.86)	2.86$_{1,2,4,5,6}$ (1.08)	2.29$_{1,2,3,5,6}$ (0.99)	3.17$_{1,2,3,4,6}$ (1.05)	1.73$_{1,2,3,4,5}$ (1.00)
	FCS**	4.23$_{2,3,4,5,6}$ (0.99)	3.49$_{1,3,4,5,6}$ (0.85)	2.93$_{1,2,4,5,6}$ (1.06)	2.31$_{1,2,3,5,6}$ (0.98)	3.28$_{1,2,3,4,6}$ (1.01)	1.75$_{1,2,3,4,5}$ (1.00)

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

ICE = Internal combustion engine car; PT = Public transport; BI = Bicycle; GF = Go on foot; EV = Electric vehicle (battery, hybrid and fue cell); EBI= Electric bike; AVWS = Autonomous vehicle with steering wheel; AVNS = Autonomous vehicle with no steering wheel, AVPT = Autonomous vehicle for public transport, SCS = Station-based carsharing, FCS = Free-floating carsharing; PCS = Private carsharing, RS = Ride sharing

Note: Numbers in subscript indicate which variable means of clusters differ significantly (MANOVA post hoc analysis (Tukey test); $p < 0.05$). For example, the superscript number $_{3}$ in the first cell indicates that cluster 1 differs significantly from cluster 3 in its attitude towards ICE cars.

Table A2: Relevance of transport mode attributes for each segment

	Cluster					
	1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Independence**	4,85$_{4,5}$ (1,30)	4,97$_{3}$ (1,17)	4,72$_{2,4,5,6}$ (1,25)	5,08$_{1,3}$ (1,19)	5,08$_{1,3}$ (1,13)	4,98$_{3}$ (1,37)
Comfort**	4,29$_{3}$ (1,27)	4,33$_{3,5}$ (1,08)	4,07$_{1,2,4,6}$ (1,13)	4,39$_{3,5}$ (1,21)	4,17$_{2,4}$ (1,10)	4,28$_{3}$ (1,38)
Cost efficiency **	4,88$_{3,4,6}$ (1,23)	4,72 (1,14)	4,63$_{5}$ (1,23)	4,60$_{1,5}$ (1,27)	4,83$_{3,4,6}$ (1,15)	4,55$_{1,5}$ (1,37)
Environmental friendliness**	4,55$_{2,3,4,5,6}$ (1,30)	4,19$_{1,4,6}$ (1,11)	4,08$_{1,5,6}$ (1,18)	3,98$_{1,2,5,6}$ (1,27)	4,27$_{1,3,4,6}$ (1,13)	3,74$_{1,2,3,4,5}$ (1,51)
Safety**	4,95 (1,32)	4,93$_{3}$ (1,17)	4,80$_{2,4,5}$ (1,26)	4,98$_{3}$ (1,20)	5,02$_{3}$ (1,14)	4,89 (1,37)
Driving experience**	4,04$_{3}$ (1,41)	3,93$_{3}$ (1,27)	3,77$_{1,2,4,5,6}$ (1,26)	4,06$_{3}$ (1,34)	3,93$_{3}$ (1,32)	4,12$_{3}$ (1,52)
Time efficiency**	4,76$_{3}$ (1,30)	4,78$_{3}$ (1,16)	4,53$_{1,2,4,5,6}$ (1,24)	4,72$_{3}$ (1,28)	4,76$_{3}$ (1,17)	4,73$_{3}$ (1,38)
Expression of lifestyle**	3,82$_{2,3,4,5,6}$ (1,38)	3,57$_{1,3,5,6}$ (1,18)	3,35$_{1,2}$ (1,18)	3,51$_{2,}$ (1,32)	3,30$_{1,2,4}$ (1,26)	3,31$_{1,2}$ (1,45)

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

Note: Numbers in subscript indicate which variable means of clusters differ significantly (MANOVA post hoc analysis (Tukey test); $p < 0.05$). For example, the superscript number $_{4}$ in the first cell indicates that cluster 1 differs significantly from cluster 4 in terms of the personal relevance of the attribute independence.

** $p < .01$

Table A3: Party affiliation of segments in %

		Cluster						
		1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)	Total sample
Party**	CDU/CSU	17.7%	20.6%	17.1%	17.8%	18.9%	16.9%	18.2%
	SPD	19.6%	17.1%	14.2%	14.9%	15.9%	18.4%	16.0%
	FDP	4.7%	4.8%	3.9%	4.8%	4.2%	3.0%	4.3%
	Die Linke	11.7%	9.9%	8.7%	8.5%	10.1%	7.1%	9.3%
	GRÜNE	16.2%	15.2%	8.7%	9.5%	13.7%	4.5%	11.3%
	PIRATEN	2.8%	3.3%	1.9%	1.3%	2.2%	1.1%	2.2%
	AfD	9.7%	7.4%	9.3%	17.7%	9.6%	17.7%	10.6%
	other parties	2.4%	3.2%	3.4%	3.0%	2.5%	5.6%	3.3%
	Don´t know	8.1%	10.1%	14.8%	9.5%	11.0%	9.3%	11.6%
	Not spezified	7.1%	8.3%	17.9%	13.1%	12.3%	16.4%	13.3%

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

* $p < .05$
** $p < .01$

Table A4: Psychological characteristics of segments, i.e., value orientation, innovativeness, opinion leadership, tendency of risk taking, life satisfaction

		Cluster					
		1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Value orientation	Power*	$3.54_{2,3,4,5,6}$ (1.41)	$3.01_{1,3,5,6}$ (1.26)	$2.86_{1,2}$ (1.18)	$2.92_{1,6}$ (1.22)	$2.74_{1,2}$ (1.26)	$2.69_{1,2,4}$ (1.46)
	Achievement*	$4.37_{2,3,4,5,6}$ (1.19)	$4.05_{1,3,4,5,6}$ (1.11)	$3.65_{1,2,5}$ (1.17)	$3.80_{1,2,6}$ (1.27)	$3.88_{1,2,3,4,6}$ (1.17)	$3.48_{1,2,3,4,5}$ (1.51)
	Hedonism*	$4.18_{2,3,4,5,6}$ (1.20)	$3.91_{1,3,4,6}$ (1.08)	$3.59_{1,2,5,6}$ (1.19)	$3.68_{1,2,6}$ (1.22)	$3.77_{1,3,6}$ (1.25)	$3.34_{1,2,3,4,5}$ (1.49)
	Stimulation **	$4.41_{2,3,4,5,6}$ (1.15)	$4.00_{1,3,4,5,6}$ (1.08)	$3.62_{1,2,5,6}$ (1.17)	$3.66_{1,2,6}$ (1.19)	$3.81_{1,2,3,6}$ (1.22)	$3.34_{1,2,3,4,5}$ (1.44)
	Self-determination*	$5.02_{3,4,6}$ (1.02)	$4.99_{3,4,6}$ (0.96)	$4.45_{1,2,4,5}$(1.24)	$4.82_{1,2,3,5,6}$ (1.15)	$5.07_{3,4,6}$ (1.00)	$4.37_{1,2,4,5}$ (1.60)
	Universalism **	$4.97_{3,4,6}$ (1.06)	$4.88_{3,4,6}$ (1.00)	$4.35_{1,2,5,6}$ (1.23)	$4.42_{1,2,5,6}$ (1.20)	$4.91_{3,4,6}$ (1.09)	$3.98_{1,2,3,4,5}$ (1.58)
	Benevolence*	$4.87_{3,4,6}$ (1.01)	$4.78_{3,4,6}$ (0.94)	$4.32_{1,2,4,5,6}$ (1.18)	$4.47_{1,2,3,5,6}$ (1.12)	$4.86_{3,4,6}$ (0.98)	$4.07_{1,2,3,4,5}$ (1.53)
	Tradition**	$4.25_{2,3,4,5,6}$ (1.33)	$3.98_{1,3,6}$ (1.29)	$3.77_{1,2,5}$ (1.29)	3.91_{1} (1.41)	$3.98_{2,3,6}$ (1.30)	$3.70_{1,2,5}$ (1.67)
	Conformity*	$4.10_{2,3,4,5,6}$ (1.34)	$3.91_{1,3,4,6}$ (1.17)	$3.60_{1,2,5,6}$ (1.22)	$3.68_{1,2,6}$ (1.24)	$3.85_{1,3,6}$ (1.28)	$3.40_{1,2,3,4,5}$ (1.54)
	Security**	$4.93_{3,4,6}$ (1.06)	$4.87_{3,4,6}$ (0.96)	$4.41_{1,2,4,5}$ (1.22)	$4.66_{1,2,3,5,6}$ (1.15)	$4.94_{3,4,6}$ (1.01)	$4.30_{1,2,4,5}$ (1.59)
Innovativeness**		$4.01_{2,3,4,5,6}$ (0.86)	$3.72_{1,3,4,5,6}$ (0.80)	$3.17_{1,2,5,6}$ (0.82)	$3.19_{1,2,6}$ (0.92)	$3.30_{1,2,3,6}$ (0.83)	$2.78_{1,2,3,4,5}$ (0.90)
Opinion leadership**		$3.81_{2,3,4,5,6}$ (0.86)	$3.52_{1,3,4,5,6}$ (0.80)	$3.07_{1,2,5,6}$ (0.77)	$3.09_{1,2,5,6}$ (0.88)	$3.26_{1,2,3,4,6}$ (0.85)	$2.78_{1,2,3,4,5}$ (0.85)
Risk taking*		$4.38_{2,3,4,5,6}$ (1.37)	$4.02_{1,3,4,6}$ (1.27)	$3.72_{1,2,5,6}$ (1.28)	$3.82_{1,2,6}$ (1.44)	$3.92_{1,3,6}$ (1.25)	$3.52_{1,2,3,4,5}$ (1.51)
Life satisfaction*		$5.07_{2,3,4,5,6}$ (1.40)	$4.84_{1,3}$ (1.39)	$4.61_{1,2,4}$ (1.43)	$4.84_{1,3}$ (1.49)	4.73_{1} (1.41)	4.70_{1} (1.71)

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

Note: Numbers in subscript indicate which variable means of clusters differ significantly (MANOVA post hoc analysis (Tukey test); $p < 0.05$). For example, the superscript number $_2$ in the first cell indicates that cluster 1 differs significantly from cluster 2 in terms of the importance of the value power.

* $p < .05$
** $p < .01$

Table A5.1: Self-reported knowledge about travel innovations

			Cluster					
			1 (EL)	2 (IP)	3 (CP)	4 (CI)	5 (CD)	6 (RT)
Knowledge about	EV**	No Knowledge	14,6%	9,0%	34,4%	19,3%	15,8%	46,9%
		Heard about	29,5%	32,0%	38,5%	38,7%	38,1%	32,4%
		Read about	32,6%	39,3%	20,9%	28,0%	34,2%	14,7%
		Familiar with	17,3%	15,3%	5,4%	11,9%	11,0%	5,0%
		Competent	5,0%	3,6%	0,6%	2,1%	0,7%	0,9%
		Expert	1,0%	0,7%	0,2%	0,0%	0,1%	0,2%
	EBI**	No Knowledge	13,0%	11,8%	34,6%	23,2%	14,1%	47,7%
		Heard about	31,3%	36,1%	37,8%	38,8%	40,4%	32,6%
		Read about	29,5%	32,7%	19,8%	24,7%	29,9%	12,5%
		Familiar with	18,0%	15,8%	7,0%	11,2%	12,8%	6,0%
		Competent	7,1%	3,1%	0,7%	1,8%	2,0%	0,6%
		Expert	1,1%	0,5%	0,1%	0,3%	0,9%	0,4%
	AVWS**	No Knowledge	29,0%	24,4%	54,5%	43,9%	38,0%	65,9%
		Heard about	33,9%	42,1%	32,6%	34,7%	44,9%	23,5%
		Read about	22,9%	24,3%	10,7%	15,8%	14,7%	8,0%
		Familiar with	10,4%	6,9%	1,6%	4,2%	1,7%	1,5%
		Competent	3,4%	1,8%	0,5%	1,3%	0,5%	0,9%
		Expert	0,5%	0,5%	0,0%	0,1%	0,1%	0,2%
	AVNS**	No Knowledge	33,5%	33,1%	60,9%	53,7%	48,9%	67,2%
		Heard about	33,5%	38,1%	27,2%	30,2%	34,8%	24,0%
		Read about	20,1%	22,0%	9,8%	10,6%	13,5%	5,6%
		Familiar with	9,2%	5,2%	1,5%	4,2%	2,1%	2,4%
		Competent	2,9%	1,2%	0,5%	1,0%	0,5%	0,6%
		Expert	0,6%	0,3%	0,1%	0,3%	0,2%	0,2%
	AVPT**	No Knowledge	40,4%	49,5%	67,6%	63,8%	64,4%	76,5%
		Heard about	28,8%	29,9%	21,7%	23,5%	25,1%	15,1%
		Read about	17,2%	15,1%	7,3%	9,5%	8,9%	5,0%
		Familiar with	8,6%	4,2%	2,3%	2,7%	1,4%	3,0%
		Competent	3,6%	1,1%	0,5%	0,3%	0,1%	0,4%
		Expert	1,5%	0,2%	0,5%	0,1%	0,1%	0,0%
	SCS**	No Knowledge	30,0%	34,8%	60,9%	57,6%	41,0%	71,1%
		Heard about	33,2%	40,6%	26,7%	30,4%	37,8%	21,6%
		Read about	16,0%	15,8%	8,4%	8,5%	13,8%	4,3%
		Familiar with	15,6%	7,7%	3,2%	3,4%	6,2%	2,6%
		Competent	4,5%	0,5%	0,6%	0,0%	1,0%	0,4%
		Expert	0,6%	0,5%	0,2%	0,1%	0,2%	0,0%
	FCS**	No Knowledge	30,3%	35,1%	56,5%	55,4%	35,6%	72,1%
		Heard about	32,6%	39,5%	31,5%	30,7%	40,9%	19,4%
		Read about	17,3%	17,0%	8,1%	9,4%	16,8%	6,0%
		Familiar with	15,2%	7,2%	3,2%	4,2%	5,8%	1,7%
		Competent	3,7%	1,1%	0,6%	0,4%	0,9%	0,4%
		Expert	0,8%	0,2%	0,1%	0,0%	0,1%	0,2%

EL = *Eco-oriented opinion leaders;* IP = *Innovation-oriented progressives;* CP = *Cost-conscious pragmatics;* CI = *Comfort-oriented individualists;* CD = *Common good-oriented city dwellers;* RT = *Risk-averse traditionalist*

EV = Electric vehicle (battery, hybrid and fuel cell); EBI= Electric bike; AVWS = Autonomous vehicle with steering wheel; AVNS = Autonomous vehicle with no steering wheel, AVPT = Autonomous vehicle for public transport, SCS = Station-based carsharing, FCS = Free-floating carsharing;

References

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2007). The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. *Journal of Environmental Psychology*, *27*(4), 265–276. https://doi.org/10.1016/J.JENVP.2007.08.002

Adnan, N., Nordin, S. M., Rahman, I., Vasant, P. M., & Noor, A. (2017). A comprehensive review on theoretical framework-based electric vehicle consumer adoption research. *International Journal of Energy Research*, *41*(3), 317–335. https://doi.org/10.1002/er.3640

Ahothali, A., & Hoey, J. (2015). Good News or Bad News: Using Affect Control Theory to Analyze Readers' Reaction Towards News Articles. In *Proc. Conference of the North American Chapter of the Association for Computational Linguistics - Human Language Technologies*. Denver, CO.

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, *50*, 179–211.

Ambrasat, J. (2017). Affektive Wahrnehmung von politischen Parteien. *KZfSS Kölner Zeitschrift Für Soziologie Und Sozialpsychologie*, *69*(2), 307–330. https://doi.org/10.1007/s11577-017-0435-4

Ambrasat, J., von Scheve, C., Conrad, M., Schauenburg, G., & Schröder, T. (2014). Consensus and stratification in the affective meaning of human sociality. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(22), 8001–8006. https://doi.org/10.1073/pnas.1313321111

Anable, J., Kinnear, N., Hutchins, R., & Skippon, S. (2016). *Consumer segmentation and demographic patterns*. Transport Research Laboratory Report. Retrieved from https://trl.co.uk/reports/PPR769?reportid=7035

Anable, Jillian. (2005). 'Complacent Car Addicts' or 'Aspiring Environmentalists'? Identifying travel behaviour segments using attitude theory. *Transport Policy*, *12*(1), 65–78.

Anable, Jillian, Skippon, S., Schuitema, G., & Kinnear, N. (2012). Who will adopt Electric Vehicles ? A segmentation approach of UK consumers. In *Proceedings of European Council for an Energy Efficient Economy Summer Study*. Giens/Hyeres, France.

Axsen, J., & Kurani, K. S. (2012). Interpersonal influence within car buyers' social networks: applying five perspectives to plug-in hybrid vehicle drivers. *Environment and Planning A*, *44*(5), 1047–1065. https://doi.org/10.1068/a43221

Barbarossa, C., Beckmann, S. C., De Pelsmacker, P., Moons, I., & Gwozdz, W. (2015). A self-identity based model of electric car adoption intention: A cross-cultural comparative study. *Journal of Environmental Psychology*, *42*, 149–160. https://doi.org/10.1016/j.jenvp.2015.04.001

Barbarossa, C., De Pelsmacker, P., & Moons, I. (2017). Personal Values, Green Self-identity and Electric Car Adoption. *Ecological Economics*, *140*, 190–200. https://doi.org/10.1016/j.ecolecon.2017.05.015

Barthes, R. (1967). *Elements of Semiology*. (trans. Annette Lavers and Colin Smith, Ed.). New York: Hill & Wang.

Beierlein, C., Kovaleva, A., László, Z., Kemper, C. J., & Rammstedt, B. (2015). Kurzskala zur Erfassung der Allgemeinen Lebenszufriedenheit (L-1). https://doi.org/10.6102/zis229

Bento AM, Hughes JE, K. D. (2013). Carpooling and driver responses to fuel price changes: evidence from traffic flows in Los Angeles. *Journal of Urban Economics*, *77*, 41–56.

Bergstad, C. J., Gamble, A., Hagman, O., Polk, M., Gärling, T., & Olsson, L. E. (2011). Affective–symbolic and instrumental–independence psychological motives mediating effects of socio-demographic variables on daily car use. *Journal of Transport Geography*, *19*(1), 33–38.

Binder, A. R., Cacciatore, M. A., Scheufele, D. A., Shaw, B. R., & Corley, E. A. (2012). Measuring risk/benefit perceptions of emerging technologies and their potential impact on communication of public opinion toward science. *Public Understanding of Science*, *21*(7), 830–847. https://doi.org/10.1177/0963662510390159

Biresselioglu, M. E., Demirbag Kaplan, M., & Yilmaz, B. K. (2018). Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes. *Transportation Research Part A: Policy and Practice*, *109*, 1–13. https://doi.org/10.1016/j.tra.2018.01.017

Blumer, H. (1986). *Symbolic interactionism: Perspective and method*. University of California Press.

Boer, D. (2013). SSVS-G. Deutsche Kurzskala des Wertefragebogens von S.H. Schwartz (Short Schwartz's Value Survey). In C. Kemper, M. Zenger, & E. Brähler (Eds.), *Handbuch Kurzskalen psychologischer Merkmale*. Berlin, Germany: Medizinisch-Wissenschaftlichen Verlagsgesellschaft.

Bösehans, G., & Walker, I. (2018). Do supra - modal traveller types exist ? A travel behaviour market segmentation using Goal framing theory. *Transportation*, (Anable 2005). https://doi.org/10.1007/s11116-018-9874-7

Burgess, J., Harrison, C. M., & Filius, P. (1998). Environmental Communication and the Cultural Politics of Environmental Citizenship. *Environment and Planning A*, *30*(8), 1445–1460. https://doi.org/10.1068/a301445

Burke, P. J., & Stets, J. E. (2009). *Identity Theory*. New York: Oxford University Press.

Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A., & Goodwin, P. (2008). Smarter Choices: Assessing the Potential to Achieve Traffic Reduction Using 'Soft Measures.' *Transport Reviews*, *28*(5), 593–618. https://doi.org/10.1080/01441640801892504

Caldas, M. M., Sanderson, M. R., Mather, M., Daniels, M. D., Bergtold, J. S., Aistrup, J., … Lopez-Carr, D. (2015). Opinion: Endogenizing culture in sustainability science research and policy. *Proceedings of the National Academy of Sciences*, *112*(27), 8157–8159. https://doi.org/10.1073/pnas.1510010112

Chan, N. D., & Shaheen, S. A. (2012). Ridesharing in north america: Past, present, and future. *Transport Reviews*, *32*(1), 93–112.

Chapman, L. (2007). Transport and climate change: a review. *Journal of Transport Geography*, *15*(5), 354–367. https://doi.org/10.1016/j.jtrangeo.2006.11.008

Chng, S., Abraham, C., White, M. P., Hoffmann, C., & Skippon, S. (2017). Psychological theories of car use: An integrative review and conceptual framework. *Journal of Environmental Psychology*, *55*, 23–33. https://doi.org/10.1016/j.jenvp.2017.10.009

Coleman, N. V., & Williams, P. (2013). Feeling Like My Self: Emotion Profiles and Social Identity. *Journal of Consumer Research*, *40*(2), 203–222. https://doi.org/10.1086/669483

Cools, M., Moons, E., Janssens, B., & Wets, G. (2009). Shifting towards environment-friendly modes: Profiling travelers using Q-methodology. *Transportation*, *36*(4), 437–453. https://doi.org/10.1007/s11116-009-9206-z

Corner, A., & Randall, A. (2011). Selling climate change? The limitations of social marketing as a strategy for climate change public engagement. *Global Environmental Change*, *21*(3), 1005–1014. https://doi.org/10.1016/j.gloenvcha.2011.05.002

Creutzig, F., Fernandez, B., Haberl, H., Khosla, R., Mulugetta, Y., & Seto, K. C. (2016). Beyond Technology: Demand-Side Solutions for Climate Change Mitigation. *Annual Review of Environment and Resources*, *41*(1), 173–198. https://doi.org/10.1146/annurev-environ-110615-085428

Creutzig, F., Jochem, P., Edelenbosch, O. Y., Mattauch, L., van Vuuren, D. P., McCollum, D., & Minx, J. (2015). Energy and environment. Transport: A roadblock to climate change mitigation? *Science (New York, N.Y.)*, *350*(6263), 911–912. https://doi.org/10.1126/science.aac8033

Creutzig, F., Roy, J., Lamb, W. F., Azevedo, I. M. L., & Bruin, W. B. De. (2018). Towards demand-side solutions for mitigating climate change. *Nature Climate Change*, *8*(4), 260–271.

Dibb, S., & Stern, P. (1995). Questioning the reliability of market segmentation techniques. *Omega*, *23*(6), 625–636. https://doi.org/10.1016/0305-0483(95)00042-9

Dietz, T., Leshko, C., & McCright, A. M. (2013). Politics shapes individual choices about energy efficiency. *Proceedings of the National Academy of Sciences*, *110*(23), 9191–9192. https://doi.org/10.1073/pnas.1307484110

Dittmar, H. (1992). *The social psychology of material possessions: To have is to be*. Harvester Wheatsheaf and St. Martin's Press.

EDTA. (2018). Electric Drive Transportation Association. Retrieved August 29, 2018, from https://electricdrive.org

EVWSD. (2018). The Electric Vehicle World Sales Database. Retrieved August 29, 2018, from http://www.ev-volumes.com

Fernando, J. W., Kashima, Y., & Laham, S. M. (2014). Multiple emotions: A person-centered approach to the relationship between intergroup emotion and action orientation. *Emotion*, *14*(4), 722–732. https://doi.org/10.1037/a0036103

Finegan, E. (2008). *Language: Its Structure and Use*. Boston, MA: Wadsworth Publishing Company.

Gatersleben, B. (2014). Psychological Motives for Car Use. In T. Gärling, D. Ettema, & M. Friman (Eds.), *Handbook of Sustainable Travel*. Springer. https://doi.org/10.1007/978-94-007-7034-8

Gnambs, T., & Batinic, B. (2011). Evaluation of measurement precision with Rasch-type models: The case of the short Generalized Opinion Leadership Scale. *Personality and Individual Differences*, *50*(1), 53–58. https://doi.org/10.1016/j.paid.2010.08.021

Gössling, S., & Metzler, D. (2017). Germany's climate policy: Facing an automobile dilemma. *Energy Policy*, *105*(May 2016), 418–428. https://doi.org/10.1016/j.enpol.2017.03.019

Haustein, S., & Hunecke, M. (2013). Identifying target groups for environmentally sustainable transport: Assessment of different segmentation approaches. *Current Opinion in Environmental Sustainability*, *5*(2), 197–204. https://doi.org/10.1016/j.cosust.2013.04.009

Haustein, S., & Nielsen, T. A. S. (2016). European mobility cultures: A survey-based cluster analysis across 28 European countries. *Journal of Transport Geography*, *54*, 173–180. https://doi.org/10.1016/j.jtrangeo.2016.05.014

Heffner, R. R., Kurani, K. S., & Turrentine, T. S. (2007). Symbolism in California's early market for hybrid electric vehicles. *Transportation Research Part D: Transport and Environment*, *12*(6), 396–413. https://doi.org/10.1016/j.trd.2007.04.003

Heise, D. R. (2007). *Expressive order: Confirming sentiments in social action*. New York: Springer.

Heise, D. R. (2010). *Surveying Cultures: Discovering Shared Conceptions and Sentiments* -. New York: John Wiley & Sons.

Hine, D. W., Reser, J. P., Morrison, M., Phillips, W. J., Nunn, P., & Cooksey, R. (2014). Audience segmentation and climate change communication: Conceptual and methodological considerations. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(4), 441–459. https://doi.org/10.1002/wcc.279

Hine, D. W., Reser, J. P., Phillips, W. J., Cooksey, R., Marks, A. D. G., Nunn, P., … Glendon, A. I. (2013). Identifying climate change interpretive communities in a large Australian sample. *Journal of Environmental Psychology*, *36*, 229–239. https://doi.org/10.1016/j.jenvp.2013.08.006

Hunecke, M., Haustein, S., Bohler, S., & Grischkat, S. (2010). Attitude-Based Target Groups to Reduce the Ecological Impact of Daily Mobility Behavior. *Environment and Behavior*, *42*(1), 3–43. https://doi.org/10.1177/0013916508319587

Hunecke, Marcel. (2015). *Mobilitätsverhalten verstehen und verändern: Psychologische Beiträge zur interdisziplinären Mobilitätsforschun*. Wiesbaden: Springer VS.

IEA. (2017). *CO2 Emissions from Fuel Combustion Highlights*. International Energy Agency, Paris. https://doi.org/10.1787/co2_fuel-2017-en

Infas, DLR, & IVT. (2018). Mobilität in Deutschland (MiD) 2017. Retrieved August 31, 2018, from http://www.mobilitaet-in-deutschland.de/pdf/infas_Mobilitaet_in_Deutschland_2017_Kurzreport.pdf

Innocenti, A., Lattarulo, P., & Pazienza, M. G. (2013). Car stickiness: Heuristics and biases in travel choice. *Transport Policy*, *25*, 158–168. https://doi.org/10.1016/J.TRANPOL.2012.11.004

IPCC. (2014). Climate Change: : Mitigation of Climate Change. In J. . Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx (Ed.), *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Jamal, A., & Al-Marri, M. (2007). Exploring the effect of self-image congruence and brand preference on satisfaction: the role of expertise. *Journal of Marketing Management*, *23*(7–8), 613–629. https://doi.org/10.1362/026725707X2266

Jenn, A., Springel, K., & Gopal, A. R. (2018). Effectiveness of electric vehicle incentives in the United States. *Energy Policy*, *119*(July 2017), 349–356. https://doi.org/10.1016/j.enpol.2018.04.065

Jensen, M. (1999). Passion and heart in transport — a sociological analysis on transport behaviour. *Transport Policy*, *6*(1), 19–33. https://doi.org/10.1016/S0967-070X(98)00029-8

Kahan, D. (2010). Fixing the communications failure. *Nature*, *463*(7279), 296–297. https://doi.org/10.1038/463296a

Kahan, D. M., Braman, D., Gastil, J., Slovic, P., & Mertz, C. K. (2007). Culture and identity-protective cognition: Explaining the white male effect in risk perception. *Journal of Empirical Law Studies*, *4*(3), 465–505. https://doi.org/10.1111/j.1740-1461.2007.00097.x

Kahan, D. M., Jenkins-Smith, H., & Braman, D. (2011). Cultural cognition of scientific consensus. *Journal of Risk Research*, *14*(2), 147–174. https://doi.org/10.1080/13669877.2010.511246

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, *2*(10), 732–735. https://doi.org/10.1038/nclimate1547

Keller, C., Bostrom, A., Kuttschreuter, M., Savadori, L., Spence, A., & White, M. (2012). Bringing appraisal theory to environmental risk perception: a review of conceptual approaches of the past 40 years and suggestions for future research. *Journal of Risk Research*, *15*(3), 237–256. https://doi.org/10.1080/13669877.2011.634523

Kosinski, M., Stillwell, D., & Graepel, T. (2013). Private traits and attributes are predictable from digital records of human behavior. *Proceedings of the National Academy of Sciences*, 2–5. https://doi.org/10.1073/pnas.1218772110

Kressmann, F., Sirgy, M. J., Herrmann, A., Huber, F., Huber, S., & Lee, D.-J. (2006). Direct and indirect effects of self-image congruence on brand loyalty. *Journal of Business Research*, *59*(9), 955–964. https://doi.org/10.1016/J.JBUSRES.2006.06.001

Langbroek, J. H. M., Franklin, J. P., & Susilo, Y. O. (2016). The effect of policy incentives on electric vehicle adoption. *Energy Policy*, *94*. https://doi.org/10.1016/j.enpol.2016.03.050

Lerner, J. S., Li, Y., Valdesolo, P., & Kassam, K. S. (2015). Emotion and decision making. *Annual Review of Psychology*, *45*(1–3), 133–155. https://doi.org/10.1016/0001-6918(80)90026-8

Leviston, Z., & Walker, I. (2012). Beliefs and Denials About Climate Change: An Australian Perspective. *Ecopsychology*, *4*(4), 277–285. https://doi.org/10.1089/eco.2012.0051

Lin, C. (2002). Segmenting customer brand preference: demographic or psychographic. *Journal of Product & Brand Management*, *11*(4), 249–268. https://doi.org/10.1108/10610420210435443

Liu, C. C., & Srivastava, S. B. (2015). Pulling Closer and Moving Apart: Interaction, Identity, and Influence in the U.S. Senate, 1973 to 2009. *American Sociological Review*, *80*(1), 192–217. https://doi.org/10.1177/0003122414564182

Lois, D., & López-Sáez, M. (2009). The relationship between instrumental, symbolic and affective factors as predictors of car use: A structural equation modeling approach. *Transportation Research Part A: Policy and Practice*, *43*(9–10), 790–799. https://doi.org/10.1016/j.tra.2009.07.008

MacKinnon, N. J., & Heise, D. R. (2010). *Self, Identity, and Social Institutions*. New York: NY: Palgrave Macmillan.

Maibach, E. W., Leiserowitz, A., Roser-Renouf, C., & Mertz, C. K. (2011). Identifying like-minded audiences for global warming public engagement campaigns: An audience segmentation analysis and tool development. *PLoS ONE*, *6*(3). https://doi.org/10.1371/journal.pone.0017571

Mathijssen, J., Janssen, M., van Bon-Martens, M., & van de Goor, I. (2012). Adolescents and alcohol: an explorative audience segmentation analysis. *BMC Public Health*, *12*(1), 742. https://doi.org/10.1186/1471-2458-12-742

Mattauch, L., Ridgway, M., & Creutzig, F. (2015). Happy or liberal? Making sense of behavior in transport policy design. *Transportation Research Part D: Transport and Environment*, *45*, 64–83. https://doi.org/10.1016/j.trd.2015.08.006

Matz, S. C., Kosinski, M., Nave, G., & Stillwell, D. J. (2017). Psychological targeting as an effective approach to digital mass persuasion. *Proceeding of the National Academy of Scienes*, 1–6. https://doi.org/10.1073/pnas.1710966114

McGowan, M., Shiu, E., & Hassan, L. M. (2017). The influence of social identity on value perceptions and intention. *Journal of Consumer Behaviour*, *16*(3), 242–253. https://doi.org/10.1002/cb.1627

McKenzie-Mohr, D. (2002). New Ways to Promote Proenvironmental Behavior: Promoting Sustainable Behavior: An Introduction to Community-Based Social Marketing. *Journal of Social Issues*, *56*(3), 543–554. https://doi.org/10.1111/0022-4537.00183

McLeay, F., Yoganathan, V., Osburg, V.-S., & Pandit, A. (2018). Risks and Drivers of Hybrid Car Adoption: A Cross-Cultural Segmentation Analysis. *Journal of Cleaner Production*, *189*, 519–528. https://doi.org/10.1016/j.jclepro.2018.04.031

Midgley, D. F., & Dowling, G. R. (1993). A Longitudinal Study of Product Form Innovation: The Interaction between Predispositions and Social Messages. *Journal of Consumer Research*, *19*(4), 611–625. https://doi.org/10.1086/209326

Miller, G. (2009). *Spent: Sex, evolution, and consumer behavior*. New York: Viking.

Moons, I., & De Pelsmacker, P. (2015). An Extended Decomposed Theory of Planned Behaviour to Predict the Usage Intention of the Electric Car: A Multi-Group Comparison. *Sustainability*, *7*(5), 6212–6245. https://doi.org/10.3390/su7056212

Morton, C., Anable, J., & Nelson, J. D. (2016). Exploring consumer preferences towards electric vehicles: The influence of consumer innovativeness. *Research in Transportation Business & Management*. https://doi.org/10.1016/j.rtbm.2016.01.007

Morton, C., Anable, J., & Nelson, J. D. (2017). Consumer structure in the emerging market for electric vehicles: Identifying market segments using cluster analysis. *International Journal of Sustainable Transportation*, *11*(6), 443–459. https://doi.org/10.1080/15568318.2016.1266533

Murtagh, N., Gatersleben, B., & Uzzell, D. (2012). Multiple identities and travel mode choice for regular journeys. *Transportation Research Part F: Traffic Psychology and Behaviour*, *15*(5), 514–524. https://doi.org/10.1016/j.trf.2012.05.002

Myers, T. A., Nisbet, M. C., Maibach, E. W., & Leiserowitz, A. A. (2012). A public health frame arouses hopeful emotions about climate change: A Letter. *Climatic Change*, *113*(3–4), 1105–1112. https://doi.org/10.1007/s10584-012-0513-6

Noppers, E. H., Keizer, K., Bockarjova, M., & Steg, L. (2015). The adoption of sustainable innovations: The role of instrumental, environmental, and symbolic attributes for earlier and later adopters. *Journal of Environmental Psychology*, *44*, 74–84. https://doi.org/10.1016/j.jenvp.2015.09.002

Noppers, E. H., Keizer, K., Bolderdijk, J. W., & Steg, L. (2014). The adoption of sustainable innovations: Driven by symbolic and environmental motives. *Global Environmental Change*, *25*, 52–62. https://doi.org/10.1016/j.gloenvcha.2014.01.012

Nordlund, A. M., & Garvill, J. (2003). Effects of values, problem awareness, and personal norm on willingness to reduce personal car use. *Journal of Environmental Psychology*, *23*(4), 339–347. https://doi.org/10.1016/S0272-4944(03)00037-9

Nyborg, B. K., Anderies, J. M., Dannenberg, A., Lindahl, T., Schill, C., Schlüter, M., … Zeeuw, A. De. (2016). Social norms as solutions. *Science*, *354*(6308), 42–43. https://doi.org/10.1126/science.aaf8317

Oliver, J. D., & Lee, S. (2010). Hybrid car purchase intentions: a cross-cultural analysis. *Journal of Consumer Marketing*, *27*(2), 96–103. https://doi.org/10.1108/07363761011027204

Osgood, C. E., May, W. H., & Murray, S. M. (1975). *Cross-cultural universals of affective meaning*. Urbana, IL: University of Illinois Press.

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The Measurement of Meaning*. Urbana: University of Illinois Press.

Osgood, C. E., & Tannenbaum, P. H. (1955). The principle of congruity in the prediction of attitude change. *Psychological Review*, *62*(1), 42–55.

Oyserman, D. (2009). Identity-based motivation: Implications for action-readiness, procedural-readiness, and consumer behavior. *Journal of Consumer Psychology*, *19*(3), 250–260. https://doi.org/10.1016/j.jcps.2009.05.008

Oyserman, D. (2017). Culture Three Ways: Culture and Subcultures Within Countries. *Annual Review of Psychology*, *68*(1), 435–463. https://doi.org/10.1146/annurev-psych-122414-033617

Pettifor, H., Wilson, C., Axsen, J., Abrahamse, W., & Anable, J. (2017). Social influence in the global diffusion of alternative fuel vehicles – A meta-analysis. *Journal of Transport Geography*, *62*(July), 247–261. https://doi.org/10.1016/j.jtrangeo.2017.06.009

Poortinga, W., & Darnton, A. (2016). Segmenting for Sustainability: The Development of a Welsh Model to Engage the Public in Sustainability and Sustainability-Related Issues. *Journal of Environmental Psychology*, *45*, 221–232. https://doi.org/10.1016/j.jenvp.2016.01.009

Prillwitz, J., & Barr, S. (2011). Moving towards sustainability? Mobility styles, attitudes and individual travel behaviour. *Journal of Transport Geography*, *19*(6), 1590–1600. https://doi.org/10.1016/j.jtrangeo.2011.06.011

Pronello, C., & Camusso, C. (2011). Travellers' profiles definition using statistical multivariate analysis of attitudinal variables. *Journal of Transport Geography*, *19*(6), 1294–1308. https://doi.org/10.1016/j.jtrangeo.2011.06.009

Reed, A. (2002). Social Identity as a Useful Perspective for Self-Concept – based Consumer Research. *Psychology & Marketing*, *19*(3), 235–266.

Reed, A., Forehand, M. R., Puntoni, S., & Warlop, L. (2012). Identity-based consumer behavior. *International Journal of Research in Marketing*, *29*(4), 310–321. https://doi.org/10.1016/j.ijresmar.2012.08.002

Rezvani, Z., Jansson, J., & Bodin, J. (2015). Advances in consumer electric vehicle adoption research : A review and research agenda. *Transportation Research Part D*, *34*, 122–136. https://doi.org/10.1016/j.trd.2014.10.010

Rogers, K. B. (2013). *Mapping the Social Ecology of Culture: Social Position, Connectedness, and Influence as Predictors of Systematic Variation in Affective Meaning*. Duke University.

Salathé, M., & Khandelwal, S. (2011). Assessing vaccination sentiments with online social media: implications for infectious disease dynamics and control. *PLoS Computational Biology*, *7*(10), e1002199. https://doi.org/10.1371/journal.pcbi.1002199

Scholl, W. (2013). The socio-emotional basis of human interaction and communication: How we construct our social world. *Social Science Information*, *52*(1), 3–33. https://doi.org/10.1177/0539018412466607

Schroder, T., Rogers, K. B., Ike, S., Mell, J. N., & Scholl, W. (2013). Affective meanings of stereotyped social groups in cross-cultural comparison. *Group Processes & Intergroup Relations*, *16*(6), 717–733. https://doi.org/10.1177/1368430213491788

Schröder, T., Stewart, T. C., & Thagard, P. (2013). Intention, Emotion, and Action: A Neural Theory Based on Semantic Pointers. *Cognitive Science*, *38*, 851–880. https://doi.org/10.1111/cogs.12100

Schröder, T., & Wolf, I. (2018). Psychologische Aspekte nachhaltiger Mobilität: Struktur und Dynamik von Einstellungen zu Mobilitätsinnovationen. In E. Bamberg & C. T. Schmitt (Eds.), *Psychologie und Nachhaltigkeit*. Berlin: Springer.

Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental , hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, *48*, 39–49.

Schwanen, T., Banister, D., & Anable, J. (2011). Scientific research about climate change mitigation in transport: A critical review. *Transportation Research Part A: Policy and Practice*, *45*(10), 993–1006. https://doi.org/10.1016/j.tra.2011.09.005

Schwartz, S. H. (2012). An Overview of the Schwartz Theory of Basic Values. *Online Readings in Psychology and Culture*, *2*(1). https://doi.org/https://doi.org/10.9707/2307-0919.1116

Shank, D. B., & Lulham, R. (2016a). Products as Affective Modifiers of Identities. *Sociological Perspectives*, *60*(1), 186–205. https://doi.org/10.1177/0731121416629996

Shank, D. B., & Lulham, R. (2016b). Symbolic Interaction with Consumer Products: An Affect Control Theory Approach. *Sociology Compass*, *10*(7), 613–622.

Sirgy, M. J. (1986). *Self-congruity: Toward a theory of personality and cybernetics*. New York, NY: Praeger.

Sirgy, M. J. (2018). Self-congruity theory in consumer behavior: A little history. *Journal of Global Scholars of Marketing Science*, *28*(2), 197–207. https://doi.org/10.1080/21639159.2018.1436981

Skippon, S., & Garwood, M. (2011). Responses to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. *Transportation Research Part D: Transport and Environment*, *16*(7), 525–531. https://doi.org/10.1016/j.trd.2011.05.005

Skippon, S. M., Kinnear, N., Lloyd, L., & Stannard, J. (2016). How experience of use influences mass-market drivers' willingness to consider a battery electric vehicle: A randomised controlled trial. *Transportation Research Part A: Policy and Practice*, *92*, 26–42. https://doi.org/10.1016/J.TRA.2016.06.034

Smith, W. R. (1956). Product Differentiation and Market Segmentation as Alternative Marketing Strategies. *Journal of Marketing*, *21*(1), 3–8.

Solomon, M. R. (1983). The Role of Products as Social Stimuli: A Symbolic Interactionism Perspective. *Journal of Consumer Research*, *10*(3), 319. https://doi.org/10.1086/208971

Steg, L. (2005). Car use: lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice*, *39*(2–3), 147–162.

Steg, L., Perlaviciute, G., & van der Werff, E. (2015). Understanding the human dimensions of a sustainable energy transition. *Frontiers in Psychology*, *6*(June), 1–17. https://doi.org/10.3389/fpsyg.2015.00805

Steg, L., Vlek, C., & Slotegraaf, G. (2001). Instrumental-reasoned and symbolic-affective motives for using a motor car. *Transportation Research Part F*, *4*, 151–169.

Stryker, S. (1980). *Symbolic Interactionism: A Social Structural Version*. Menlo Park, CA: Benjamin Cummings.

Stryker, Sheldon. (2008). From Mead to a structural symbolic interactionism and beyond. *Annual Review of Sociology*, *34*, 15–31.

Sütterlin, B., Brunner, T. A., & Siegrist, M. (2011). Who puts the most energy into energy conservation? A segmentation of energy consumers based on energy-related behavioral characteristics. *Energy Policy*, *39*(12), 8137–8152. https://doi.org/10.1016/j.enpol.2011.10.008

Sven, H., Patrick, S., & Martin, P. (2017). Ready, Steady, Green: Examining the Effectiveness of External Policies to Enhance the Adoption of Eco-Friendly Innovations. *Journal of Product Innovation Management*, *34*(3), 343–359. https://doi.org/10.1111/jpim.12364

Tran, M., Banister, D., Bishop, J. D. K., & McCulloch, M. D. (2012). Realizing the electric-vehicle revolution. *Nature Climate Change*, *2*(5), 328–333.

van der Werff, E., Steg, L., & Keizer, K. (2013). It is a moral issue: The relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. *Global Environmental Change*, *23*(5), 1258–1265. https://doi.org/10.1016/J.GLOENVCHA.2013.07.018

van Giesen, R. I., Fischer, A. R. H., van Dijk, H., & van Trijp, H. C. M. (2015). Affect and Cognition in Attitude Formation toward Familiar and Unfamiliar Attitude Objects. *Plos One*, *10*(10), e0141790. https://doi.org/10.1371/journal.pone.0141790

Vergis, S., & Chen, B. (2015). Comparison of plug-in electric vehicle adoption in the United States: A state by state approach. *Research in Transportation Economics*, *52*, 56–64. https://doi.org/https://doi.org/10.1016/j.retrec.2015.10.003

Walker, J. L., & Li, J. (2007). Latent lifestyle preferences and household location decisions. *Journal of Geographical Systems*, *9*(1), 77–101. https://doi.org/10.1007/s10109-006-0030-0

Wang, S., Li, J., & Zhao, D. (2017). The impact of policy measures on consumer intention to adopt electric vehicles: Evidence from China. *Transportation Research Part A: Policy and Practice*, *105*, 14–26. https://doi.org/10.1016/j.tra.2017.08.013

Wang, Susie, Leviston, Z., Hurlstone, M., Lawrence, C., & Walker, I. (2018). Emotions predict policy support: Why it matters how people feel about climate change. *Global Environmental Change*, *50*(January), 25–40. https://doi.org/10.1016/j.gloenvcha.2018.03.002

White, L. V., & Sintov, N. D. (2017). You are what you drive: Environmentalist and social innovator symbolism drives electric vehicle adoption intentions. *Transportation Research Part A: Policy and Practice*, *99*, 94–113. https://doi.org/10.1016/j.tra.2017.03.008

Whitmarsh, L., & O'Neill, S. (2010). Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology*, *30*(3), 305–314. https://doi.org/10.1016/j.jenvp.2010.01.003

Wolf, I., & de Haan, G. (2013). Der simulierte Kunde - Computerbasierte Marktanalyse am Beispiel von Elektromobilität. In J. Gausemaier (Ed.), *Vorausschau und Technologieplanung, 9. Symposium für Vorausschau und Technologieplanung* (pp. 279–300). Berlin: Vorausschau und Technologieplanung, 9. Symposium für Vorausschau und Technologieplanung.

7 Studie 3 – Makroebene: Changing minds about electric cars: An empirically grounded agent-based modeling approach

Veröffentlicht als:

Wolf, I., Schröder, T., Neumann, J., & de Haan, G. (2015). Changing minds about electric cars: An empirically grounded agent-based modeling approach. *Technological Forecasting & Social Change*, *94*, 269–285. https://doi.org/10.1016/j.techfore.2014.10.010

Abstract

The diffusion of electric vehicles (EVs) is considered an effective policy strategy to meet greenhouse gas reduction targets. For large-scale adoption, however, demand-side oriented policy measures are required, based on consumers' transport needs, values and social norms. We introduce an empirically grounded, spatially explicit, agent-based model, *InnoMIND* (*Inno*vation diffusion driven by changing *MIND*s), to simulate the effects of policy interventions and social influence on consumers' transport mode choices. The agents in this model represent individual consumers. They are calibrated based on empirically derived attributes and characteristics of survey respondents. We model agent decision-making with artificial neural networks that account for the role of emotions in information processing. We present simulations of 4 scenarios for the diffusion of EVs in the city of Berlin, Germany (3 policy scenarios and 1 base case). The results illustrate the varying effectiveness of measures in different market segments and the need for appropriate policies tailored to the heterogeneous needs of travelers. Moreover, the simulations suggest that introducing an exclusive zone for EVs in the city would accelerate the early-phase diffusion of EVs more effectively than financial incentives only.

Keywords

Electric vehicles, innovation diffusion, emotion, agent-based model, parallel constraint satisfaction network, social influence

Introduction

Electric vehicles (EVs– Plug-in hybrid and battery electric vehicles) are seen as a promising technology to reduce carbon emissions and achieve the transition to more sustainable transport. Comprehensive investment in research and development, e.g. in battery technology, is essential to achieve these goals, but technological development alone will not ensure the large-scale diffusion of such innovations. For successful dissemination of new technologies it is also necessary to address the demand side (e.g. Ozaki & Sevastyanova, 2011; Schuitema, Anable, Skippon, & Kinnear, 2012; Tran, Banister, Bishop, & McCulloch, 2012). To this end, we have developed an agent-based model of consumer perceptions and decisions related to innovation adoption in sustainable transport.

While focused on EVs as a technological innovation, our model also helps to answer questions about broader social innovations; i.e., changes in habits and behavioral patterns related to transport. In particular, increasing the use of public transport, bicycles, and car sharing is considered by some as the more important challenge when it comes to organizing the societal transition to more sustainable transport (e.g., Graham-Rowe, Skippon, Gardner, & Abraham, 2011; Kemp & J., 2004; Köhler et al., 2009; Nykvist & Whitmarsh, 2008). Even more than technology adoption, large-scale changes in behavioral patterns depend on the decisions of individual consumers. Numerous studies in psychology have addressed environmental decision-making at the level of individual minds (e.g., Bamberg, 2006; Collins, 2005; Fujii, 2007; Hunecke, Blobaum, Matthies, & Hoger, 2001; Klöckner & Blöbaum, 2010; Steg, 2005; van der Werff, Steg, & Keizer, 2013), but these studies often ignore the complex interactions with broader societal developments.

Agent-based models (ABMs) are considered promising tools to study multi-level interactions between individual behaviors and social dynamics (e.g., Bonabeau, 2002; Epstein & Axtell, 1996; Helbing, 2012; Homer-Dixon et al., in press). Phenomena at the group or societal level (e.g., innovation diffusion) are treated as emerging from multiple interactions of relatively simple behaviors or decisions at the individual level (e.g., changing attitudes). ABMs have become increasingly popular in studies of innovation diffusion in general and research on environmental innovations like alternative fuel vehicles in particular (e.g., Brown, 2013; Eppstein, Grover, Marshall, & Rizzo, 2011; Higgins, Paevere, Gardner, & Quezada, 2012; Shafiei et al., 2012; Sullivan, Salmeen, & Simon, 2009; Tran, 2012a, 2012b; Zhang, Gensler, & Garcia, 2011).

This work answers recent calls for more psychologically realistic models of decision making in ABMs of innovation and opinion diffusion (Kiesling et al., 2011; Sobkowicz, 2009; F. Squazzoni, Jager, & Edmonds, 2013; Sun, 2012). The decision and communication mechanisms implemented in our model are based on recent advances in understanding the role of emotion in human decision-making and communication. The contribution of the present research is thus twofold: (1) We provide novel insights relevant to practical challenges in energy transitions. (2) We demonstrate how realistic models of the mind can inform the strategic decisions of policy-makers and business managers.

The novel ABM, which we describe in the following sections, explains how patterns of belief change and innovation diffusion in social systems emerge from psychological processes such as attitudes, values, emotions, social norms, and identity (e.g. Fishbein & Ajzen, 2010; Gigerenzer & Goldstein, 1996; Homer-Dixon et al., 2013; Kahnemann, 2011; Loewenstein, Weber, Hsee, & Welch, 2001; Mehrabian & Wetter, 1987; Thagard & Kroon, 2006; Thagard, 2006). The model demonstrates how the current structure of mental representations, psychological needs, and social values creates path dependencies and constraints on future possibilities for social change and energy transitions. Based on state-of-the-art theorizing in cognitive science, and grounded in empirical data from focus groups, a representative survey, and a vignette experiment (Wolf, Hatri, Schröder, Neumann, & de Haan, forthcoming; Wolf, Schröder, Neumann, Hoffmann, & de Haan, forthcoming), the ABM can be used to generate psychologically plausible scenarios for innovation adoption. As a case study, we have focused on the city of Berlin, one of the four regions in Germany under the federal government's "Showcase of Electric Vehicles" initiative (NPE, 2012).

The remainder of this paper is structured as follows. Section 2 deals with the model architecture. We explain mechanisms for individual decision-making based on emotional coherence (Section 2.1), for the flows of information based on homophily in social networks (Section 2.2), and for the change of mental representations based on the communication of facts and emotions (Section 2.3). Section 2.4 summarizes the overall algorithm of our model. Section 3 describes the results of the model validation (Section 3.1), a baseline diffusion scenario for different types of consumers (Section 3.2), and simulations of policy scenarios related to the dissemination of EVs (Section 3.3). Finally, in Section 4, we summarize key findings, discuss limitations and practical implications, and provide suggestions for future research.

The Agent-Based Model: Design and Methods

In this section, we describe our theory of innovation adoption and its implementation in an agent-based model. This theory follows a more general multi-level approach to the study of belief change in complex social systems (Homer-Dixon et al., in press). We think that peoples' individual decisions about transport result from maximizing the satisfaction of constraints given by their mental representations, which include emotions, needs, priorities, possible actions, and knowledge about the extent to which the different actions facilitate the needs. This mechanism is called emotional coherence and modeled with localist neural networks capable of processing emotions (Paul Thagard, 2006). The adoption of innovation occurs when people change their mental representations as a result of obtaining new information through communication with others or media campaigns, but this is constrained by the compatibility of the new information with the existing mental representations. The model has a mechanism for specifying which two agents communicate with each other at any time step. This mechanism is based on sociological theorizing about homophily in social networks (e.g., McPherson, Smith-Lovin, & Cook, 2001), predicting that the likelihood of two agents exchanging information is dependent on their similarity along socio-demographic variables. In addition, we take into account geographical proximity and individual sociability for modeling social tie formation. For agent-to-agent communication, we assume in our model two possible mechanisms, in line with dual-process models of persuasion from social psychology (e.g., Chaiken, 1987; Chen & Chaiken, 1999; Petty & Cacioppo, 1986).The first mechanism is "cold" and changes the agents' factual knowledge about contingencies between actions and needs. The second mechanism is "hot" and changes the emotional values attached to the different actions. The following sections elaborate on each of these mechanisms.

Agent Decision-Making: Emotional Coherence

Mental representations can be construed as networks of constraints (Paul Thagard, 2000, 2006). Positive constraints are given by elements that go together. For example, taking the bus facilitates the needs of being environmentally responsible. Negative constraints are given by elements that contradict each other. For example, taking the bus is often incompatible with the need for independence. Emotions carry information on how important specific elements are for the individual. Someone with strong environmental values will feel very positive about being environmentally responsible, but to others, the concept might be neutral or even negative.

Decision-making involves the best possible satisfaction of all the given constraints in parallel by organizing mental representations into a coherent set (Paul Thagard & Millgram, 1995). In the example, an environmentalist might decide to take the bus and come to the conclusion that absolute independence is not so important after all. This process of parallel constraint satisfaction can be modeled with connectionist networks, where the nodes are concepts or propositions, excitatory connections between nodes are positive constraints, and inhibitory connections are negative constraints. Decisions then correspond to stable patterns of activated and inhibited elements after multiple rounds of updating the activations of nodes in parallel according to their incoming connections (e.g., Bechtel & Abrahamsen, 2002; Thagard & Millgram, 1995; Thagard, 2000; for mathematical details, see the Appendix).

Emotions can be modeled within such a network by defining special valence nodes that have excitatory (inhibitory) connections with the nodes representing emotionally positive (negative) concepts (Paul Thagard, 2006). In such a HOTCO network model (for "HOT COherence"; Thagard, 2006), valences influence the activation of concept nodes to account for the crucial role of emotion in decision-making and the fundamental psychological fact that all cognition is biased by motivation (e.g., Damasio, 1994; Kunda, 1990; Loewenstein et al., 2001; Thagard, 2006). HOTCO has been applied to various phenomena such as legal decision-making, political perceptions, or religion (Schröder & Thagard, 2011; Thagard, 2003, 2006). In the present agent-based model, we used HOTCO as the basis for the individual agents' transport decisions.

Of course, environmental consciousness and independence are not the only needs that are relevant to peoples' transport decisions. In order to maximize the empirical plausibility of the HOTCO networks representing individual agents in our model, we conducted two empirical studies – qualitative and quantitative – prior to developing the model, the details of which are described elsewhere (Wolf et al., forthcoming). The first study involved four focus group discussions (*N* = 6-8 each). They provided us with a detailed, in-depth picture of people's needs regarding transport as well as their current cognitive and emotional representations of EVs and other means of travel. The architecture of our agents, which is displayed in Fig. 1, is based on the results of focus group discussions. Eight different transport needs with different emotional values are connected with five different means of transport. Green lines represent excitatory connections. For example, the agent in Fig. 1 thinks that using a car (the second box from the left in the bottom row) facilitates his need for independence (the rightmost circle in the top row), while using an electric vehicle (the fourth box in the bottom row) would impede that need.

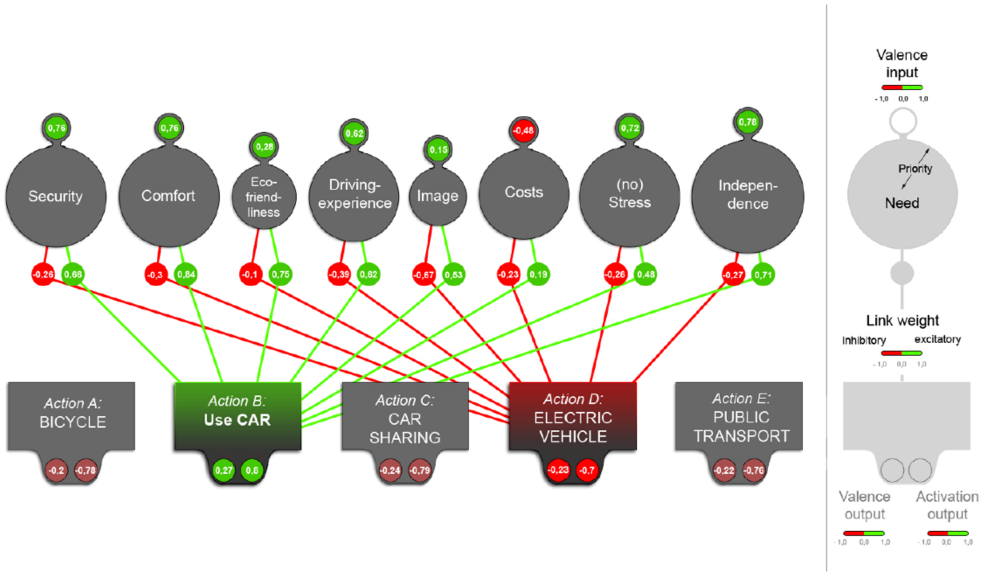

Figure 5. HOTCO emotional constraint network of transport mode decisions

Circle size indicates the priority of a need (large radius = high priority, small radius = low priority). Green (red) lines denote excitatory (inhibitory) connections. Numerical values in the upper and middle green/red circles represent empirically determined weights of emotional and cognitive links. Numerical values in the lower green/red circles denote valences and activations of different action units calculated by HOTCO. Note: For reasons of parsimony, only link weights between two modes of transport and needs are shown. In the agent-based model all five action units are linked to all needs by either inhibitory or excitatory links.

As shown in Fig.1, the agents have three types of input parameters: the priority values and emotional valences of needs and the weights of the links between needs and actions. There are two types of output parameters, the valences and activations of actions. Valences correspond to the emotions associated with the actions, while activations provide a basis for decisions. The action with the highest activation value is assumed to be the most likely one to be chosen (for technical details, see the appendix or Thagard, 2006).

For initializing and calibrating the model, the input parameters of all agents were aligned with empirical data from our second empirical study, a representative survey of the population of Berlin, Germany, with an online questionnaire (N = 675) (for details, see Wolf et al., forthcoming). The survey contained rating scales to elicit respondents' appraisals of need importance, valences, and facilitations between needs and actions (e.g., "Driving an electric vehicle offers me the flexibility I need"). For technical reasons, the individual responses were transformed to a parameter range from -1 to +1 and then implemented into the model. Thus, there is a one-to-one correspondence between the survey and the agent-based model; each survey participant is represented as an individual agent.

The agents were tagged according to the classification of their corresponding survey respondents into types of transport consumers. We performed cluster analysis of the original survey data, aimed at creating a parsimonious typology of consumers according to their transport-related needs and attitudes (for details, see Wolf , Schröder, et al., forthcoming). We found that the inhabitants of Berlin can be reasonably described as consisting of four different types, as shown in Table 1. They can be distinguished not only by their values and attitudes, but also by their behaviors (e.g., kms/year driven by car; frequency of taking the bus).

We called type 1 the *Comfort-oriented Individualists*. They have very positive emotions about cars, drive them a lot, and care relatively little about the environment. Their most important transport-related needs are comfort, autonomy, and safety. They are relatively skeptical about electric vehi-

Table 7. Sociodemographic characteristics, travel behavior and preferences of mobility types

	Type 1 Comfort-oriented Individualists	Type II Cost-Oriented Pragmatics	Type III Innovation-Oriented Progressives	Type IV Eco-Oriented Opinion Leaders
Socio-demographics				
% of total sample	15	16	34	35
Gender (% females)	55	49	48	46
Education (% graduate population)	28	26	24	31
Income				
< 2500 € p.m. (%)	76	77	74	72
> 2500 € p.m. (%)	24	23	26	28
Self-reported travel				
Kilometers by ICE[1] car				
< 15.000 per year (%)	65	89	79	87
> 15.000 per year (%)	36	11	21	13
Preferred mode of	ICE[1] car	PT[2]	ICE[1] car	PT[2]
Acceptance of EV[3]s				
Intent. to buy an EV[3] (%)	3	3	9	13
Motives of mode choice				
Most important needs	1. Independence 2. Security 3. Comfort	1. Cost 2. Security 3. Independence	1. Independence 2. Security 3. Comfort	1. Cost 2. Security 3. Eco-friendliness

1 = Internal combustion engine
2 = Public transport
3 = Electric vehicle

cles. *Cost-Oriented Pragmatics* (type 2) prefer trains and buses, although not for ideological reasons. Their most important needs are cost-efficiency and safety. Among all respondents, they are the least likely to buy an electric vehicle. *Innovation-Oriented Progressives* (type 3) drive a lot, but switch flexibly between cars and public transport. Independence, safety and cost-efficiency are the most important needs for them, when choosing a means of travel. Finally, type 4, the *Eco-Oriented Opinion Leaders* have the highest average level of education. They attach very positive emotions to bicycles, public transport, and electric vehicles.

Please note carefully that tagging the agents with a consumer type has no consequences for the behavior of the agent in the model, since all the agents were calibrated individually. However, we will use the typology below when we describe simulations, to demonstrate how technology adoption dynamics differ across agents with different mental representations to start with.

Social network structure: Who talks to whom?

Empirical research has shown that peoples' attitudes and decisions to adopt new behaviors or technologies are influenced by their social environment and network (e.g., Aral & Walker, 2012; Axsen & Kurani, 2011; Iyengar, Van den Bulte, & Valente, 2010; Valente, 1995, 2005). In our model we generated a social network structure following socio-psychological network models by Hamill et al. (2009), Edmonds (2006), and Mcpherson et al. (1991, 2001) and Blau (1977), given that our previously conducted survey (Wolf, Schröder, et al., forthcoming) did not generate network data. In our combined approach, the likelihood that two agents form a social tie and thus exchange their opinions about transport modes is a function of their geographical proximity, social reach, and socio-demographic similarity (i.e. homophily).

Before creating the interaction structure, we initialized a heterogeneous agent population of 675 agents corresponding to the characteristics of our survey respondents (for an overview of initialized parameters see Table C1 in the appendix). Therefore we used, in addition to cognitive-emotional parameters (see section 2.1.), individual socio-demographic properties and residential location of our survey respondents, as well as the affiliation to a particular mobility type.

The generation of the social network structure involved three steps. First, each agent was located on a map of Berlin based on the residential location of his real-life counterpart. Since agents do not roam during the simulation, their social reach was determined by a circle surrounding each agent, following Hamill et al. (2009). The radius of the circle comprises a range from 0 to 1 and was grounded empirically on four survey items addressing self-reported opinion-leadership (e.g., "My friends often ask me to give advice upon travel and transport issues") as well as social orientation (e.g., “Before I adopt an innovation, in general I ask the advice of my friends”). Agents with a wide social reach (i.e. radius close to 1) would thus reach more potential communications partners in the geographical neighborhood than those with a circle radius close to 0. But social contacts in this geographical-social environment are not random. Due to the homophilious nature of networks, the probability of an interaction between two agents is a declining function of distance in Blau space, that is, a n-dimensional latent social space (McPherson, 1983). To define social similarity, each agent calculated in a second step the Euclidean distance in a 6-dimensional space for all gents within its social reach. The dimensions of the socio-demographic coordinate system are defined by age, gender, income, level of education, level of modernity, and level of consumption. The location of each agent in social space depends on the characteristics on theses static attributes. This concept of Blau space follows the principle of homophily, according to which the likelihood that two individuals communicate with each other is a function of their socio-demographic similarity (Mcpherson et al., 2001). For mathematical details, see the appendix.

Information exchange between agents: “cold” and “hot” communication

Besides the agents’ individual mental representations and the flows of information at the level of the social system, we also modeled a persuasion mechanism that captures belief change as the result of immediate communication. Most psychological theories of information processing and decision-making assume some form of interaction between more deliberate, intentional and more automatic, emotion-driven processes (e.g., Deutsch & Strack, 2006; Kahnemann, 2011; Schröder, Stewart, & Thagard, forthcoming). These “cold” and “hot” aspects of cognition correspond with different variants of theorizing about two different routes to persuasion, central and systematic vs. peripheral and heuristic (e.g., Chaiken, 1987; Chen & Chaiken, 1999; Petty & Cacioppo, 1986). Loosely based on this well-established dichotomy in psychological research, we allow our agents to adapt their mental representations in communication through two different mechanisms, taken from an earlier multi-agent variant of HOTCO (Paul Thagard & Kroon, 2006). In this model, aimed at simulating decision-making in small groups, communication can be about facts (e.g., the information that a certain action will facilitate achieving the agent’s needs), and is called the means-ends mechanism. Communication can also be emotional (e.g., expressed enthusiasm or emotional attachment about one action), and is called contagion (cf. Hatfield, Cacioppo, & Rapson, 1993).

In parallel constraint satisfaction models such as Thagard’s (2006) HOTCO, belief adjustments in response to external input can be implemented by changing connection weights between elements of the network (e.g., Monroe & Read, 2008; Read & Urada, 2003; Van Overwalle & Siebler, 2005). When the constraint-satisfaction algorithm described in section 2.1 and appendix is then applied again, the network might settle in a different stable state than before. This is how we model changes in mental representation that follow agent-to-agent communication. The two communication mechanisms described above impact different sets of connection weights in the receiver neural network. Means-ends communication results in an adjustment of the links between need and action nodes (see Fig. 1). For example, one agent might transfer to the other the factual information that electric vehicles are environmentally friendly, resulting in a stronger excitatory link between the node representing the need for eco-consciousness and the node representing the action of driving an electric vehicle. Communication by emotional contagion results in an adjustment of the valences of action nodes, i.e. the connection weights between the action nodes and a special valence node in the network (for details, see section 2.1 and the appendix). For example, this valence adjustment models the enthusiasm one agent might express to the other through nonverbal cues while talking about her experience when test-driving an electric vehicle.

The parameterization of the connection weights adjustment was based on data from a separate experimental study, aimed at quantifying how people change their beliefs about EVs in response to influence of others (Wolf, Hatri, et al., forthcoming). The experiment was driven by the hypothesis that the acceptance of others' opinions and the process of belief adjustment is a matter of belief strength, emotional valence, and attitude congruence between the sender and the receiver (cf. Osgood & Tannenbaum, 1955). We studied these coherence effects in a vignette experiment by asking participants to rate their agreement and their perceived belief change on a series of unrelated statements about the use of electric vehicles and combustion engine cars. We used the experimental data to determine for different configurations of senders' belief strength and sender-receiver belief congruence the weight changes that optimized the prediction of the empirical data with our persuasion model. Details are given in the appendix.

Summary of the ABM Algorithm

Fig. 2 summarizes how the agent-based model works. At each time step of a simulation, each agent randomly chooses one communication partner out of his individual social network (Fig. 2a). Of course this a simplification of the communication processes in real life. However, we believe it is sufficiently realistic to model the relevant aspects of social influence in our approach. Time steps represent an internal system time and do not model actual physical time. The content of communication for each conversation is selective and depends on the sender's belief strength and his strength of emotional reaction to transport mode options. Thus, the speaker communicates only factual arguments (i.e. facilitation weights between need and action units) with high confidence and valence connotations of actions that are affectively rich (Fig. 2b).

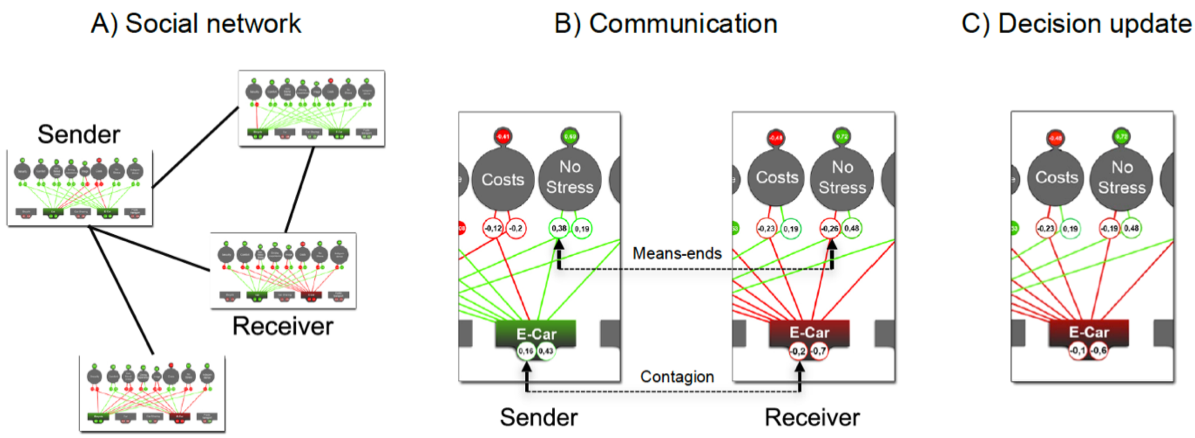

Figure 6. Illustration of the agent-based model InnoMind communication process

A) An agent randomly selects a communication partner in his personal social network. B) During communication, agents exchange factual and emotional information ("means-ends" and "contagion", respectively. C) Sender and receiver integrate the new information in their individual HOTCO network and recalculate their transportation decisions.

The crucial parts of this communication procedure are the evaluation and integration of information in the mental model of the listening agent. During each conversation, the communication partners assume the roles of speaker and listener simultaneously. Thus, belief adjustment is carried out for both agents of the dyad. Once all affected connection weights of both agents are set to their new values, agents update their decisions employing the coherence algorithm described in section 2.1 (Fig. 2c). At this stage, they might switch their preferred mode of transport, if the persuasion attempt of the other agent was successful. In the following step of the simulation, agents communicate about transport issues based on their updated mind set with their other social peers. It is important to note that preference changes in our approach represent a change of behavioral intentions rather than a mode switch on a behavioral level.

In addition to peer influence, agents can be influenced by media coverage. To simulate media campaigns about certain policy instruments we implemented a media agent affecting mental representations of agents in a similar manner as in the dyadic communication procedure described above. The media agent has directed links to an adjustable proportion of the agent population (from 0% to 100%) and transmits, at predefined time steps, facilitation weights, priorities, and emotions, depending on the content of the campaign. For example, the information about the introduction of a purchase subsidy for EVs is represented by strengthening the positive facilitation weight between the need unit *Cost* and the action unit *Option D: Electric vehicle*. Analogously to the dyadic communication mechanisms described above, affected agents integrate the information from the media agent in their connectionist network and update their decision. The relevance of received information is adjusted by a policy impact factor, derived from empirical ratings of related items in the survey described above and in Wolf et al. (forthcoming) (e.g. "Would this policy measures change your attitude toward EVs?"). Participants stated their responses on a six-point Likert scale ranging from "Absolute no influence" (1) to "Very strong influence" (6). For technical reasons, these values ware transferred to a parameter range from 0 to 1 (for an overview of mean values and a sensitivity analysis of the policy impact factor see Table C2 and Figure F1 in the appendix).

A formal, mathematical description of the agent-based model is provided in the appendix. The model was implemented in a computer program written in Java. We now turn to a description of its validation and use for simulating the diffusion of EVs under a base case as well as different policy scenarios.

Results and discussion

Validation of the decision algorithm

Prior to performing a series of simulations, we compared model predictions with data on actual transport choices from the above-mentioned empirical survey (Wolf, Schröder, et al., forthcoming), to validate the accuracy of the connectionist model. To this end, the model computed individual agents' decisions about their preferred transport modes, prior to communication, based on their empirically grounded mental representations (i.e. attitudes, priorities and emotions). Recall that each agent has a real-life counterpart in the empirical survey. For the model validation, survey participants' scores related to self-reported transport behaviors were regressed on the output parameters of the HOTCO networks representing the preferences of these respondents in the agent-based model (i.e., the activation parameters of the action nodes). Note that we calibrated the decision structure of agents exclusively by the variables representing beliefs and emotions. The data on behaviors were used only for validating the model output, but nor for calibrating the model. Social psychological research on the attitude-behavior relationship under the influential Theory of Planned Behavior (Ajzen, 1991; Fishbein & Ajzen, 2010) shows that stated intentions generally account for roughly a third of the variance in behavior (Armitage & Conner, 2001), which we thus considered as a benchmark for the predictive power of our InnoMIND model.

We performed stepwise binary logistic regressions to assess the effects of the obtained activations on the probability to use a specific transport mode. Original responses variables on five-point Likert-type scales (ranging from "I use this transport mode (almost) never" (1) to "I use this transport mode (almost) every day" (5)) were dichotomized (level 1-3 into "0 = no use" and level 4 to 5 into "1 = use") and then treated as criteria. We opted for logistic regression and dichotomization because of the non-normal distribution of the error terms in linear regression. In four separate models, we regressed travel mode choice behavior (for EVs, the intention to substitute the current main transport mode) on activations of action units of the decision model (preferences toward internal combustion engine (ICE) car, electric vehicle (EV), public transport (PT) and bicycle (BI)). Again, car sharing was excluded from the analysis due to lack of data. The results for all regression models are shown in Table 2. R square (Nagelkerke) values between 0.231 and 0.462 and percentages of correctly predicted cases varying between 68.6% for model 2 and 78.4% for model 4 indicate in comparison to the power of the established Theory of Planned Behavior (Ajzen, 1991; Fishbein & Ajzen, 2010; see Armitage & Conner, 2001 for a meta-analysis) a reasonable fit and good overall performance of the simulation model. Odds ratios (Exp(*B*)) in model 1 (Table 2) indicate that on values for ICE cars have the strongest positive effects on the actual use of ICE cars, while an increase in activations towards PT decreases the probability of car usage. Survey respondents' intentions to substitute the current main mode of transport by an EV (model 2) are significantly predicted by activations of EV action nodes in the corresponding virtual agents. Agents with preferences for public transport are less willing to use EVs, whereas attitudes towards ICE cars and bicycles had no effect on odds of this outcome. The results in model 3, predicting the frequency of public transport use, show again an inverse pattern of two predictors. Activation of PT nodes in virtual agents predicts survey counterparts' use of public transport, while high activations for ICE cars are negatively related to this travel mode use. Model 4 was designed to investigate the use of bicycle and shows high robustness in predicting this travel mode choice (78.4% correct overall; $R^2 = 0.462$). The independent variables attitudes towards EVs and public transport did not have a significant influence on the frequency of use bicycles. The likelihood of use was increased if agents favored bicycle and decreased for car-oriented agents.

Table 8. Odd ration and their related score statistics of binary logistic regression analysis

Independent variables	Model 1 Use of internal combustion engine car	Model 2 Intention to substitute current main mode of transport by EV	Model 3 Use of public transport	Model 4 Use of bicycle
HOTCO activations for:				
ICE[1] car	3.705 (0.001)	n.s.	0.407 (0.001)	0.535 (0.001)
EV[2]	1.438 (0.036)	4.820 (0.001)	n.s.	n.s.
PT[3]	0.524 (0.001)	0.665 (0.001)	3.118 (0.001)	n.s.
BI[4]	n.s	n.s	n.s	9.502 (0.001)
Constant	1.394 (0.002)	1.056 (0.534)	1.214 (0.040)	0.610 (0.001)
Model chi square	165.730	127.813	146.699	281.284
Nagelkerke´s R^2	0.298	0.231	0.261	0.462
-2 log likelihood	717.529	800.453	787.804	623.0729
% Correct overall	73.5	68.6	70.1	78.4

1 = Internal combustion engine
2 = Electric vehicle
3 = Public transport
4 = Bicycle
n.s = Not significant

Taken together, these statistical results provide evidence that the parallel constraint satisfaction network model we used is a valid approach to model individual travel mode choice behavior. This conclusion is also upheld by comparing the percentage of internal combustion engine cars as the primary means of travel predicted by the model with data on private transport share across the different districts of Berlin, taken from a recent study by the government of Berlin (Senat Administration of Berlin, 2010). The comparison is displayed in Fig. 3. It can be seen that the predictions derived from our model roughly match the observed geospatial pattern of peoples' actual transport decisions–as shown in Fig. 3b the share of internal combustion engine cars on everyday mode split–once more corroborating the validity of our modeling approach. We now turn to scenarios of future EV adoption in Berlin, which we created by simulating communication between the agents in our model.

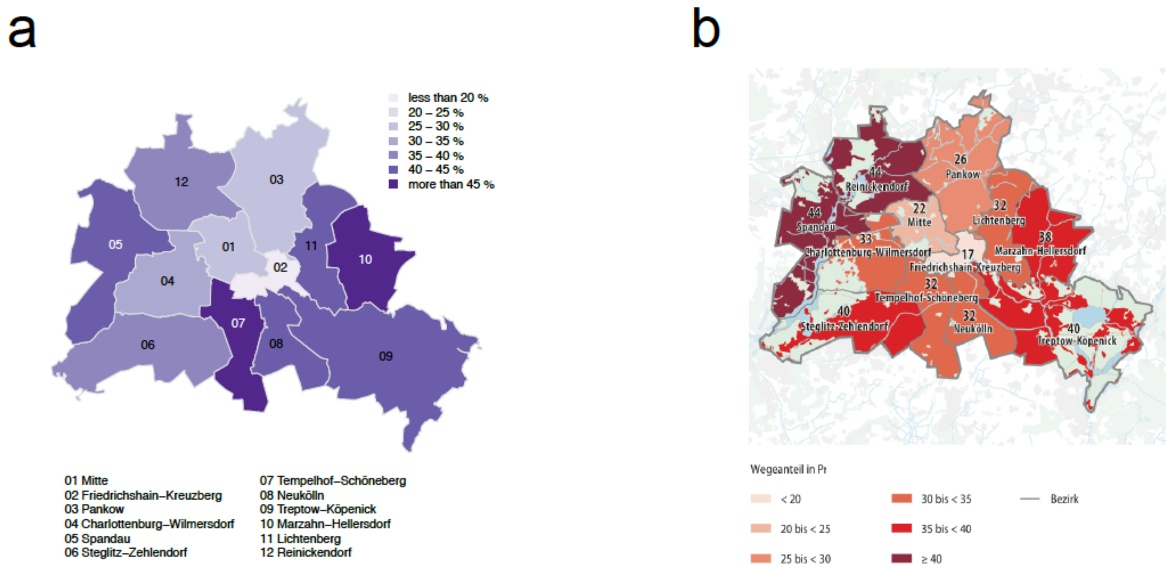

Figure 7. Districts map of Berlin

A) Percentage of agents preferring internal combustion engine (ICE) car
after initialization. Source own illustration. B) Percentage of individual internal combustion engine cars on everyday mode split across the different districts of Berlin. Source: Senat of Berlin.

Scenario descriptions and assumptions

Four scenarios, including a reference scenario, were analyzed to explore the interrelated effects of individual attitude factors (i.e. needs, emotions etc.), social influence, and policy interventions on transport choices in general and on the acceptance of electric vehicles (EVs) in particular. The scenario experiments differ with regard to assumptions we made about external influences, i.e. policy interventions and social influence, on consumers' mental representations. In the baseline scenario, communication with peers alone affected the attitudes of agents. In the policy scenarios, interventions via the media agent additionally affected attitudes toward EVs in specific ways, as described below. Note that the (external) influences of the environment did not directly affect the final decisions of agents, but instead the underlying psychological associations between transport mode options, needs, and emotions. In all scenarios, model parameters of the 675 agents were initialized with the empirical values from our online survey. Each simulation involved 100 time steps. Below, we report average results across 10 runs of the model for each scenario. Drawing on our previously identified typology of consumers, we aggregated the dynamics of consumer decisions separately for the four consumer types, as they substantially differ in their current travel behavior, needs, attitudes and potential to adopt EVs.

As a *Reference case* scenario, we first ran the simulation without any policy intervention. In this scenario, individual attitudes and emotional associations towards transport mode options are influenced only by agent-to-agent communication within the artificial social network, as discussed in section 2.2. Besides the function as reference for comparison, we used this scenario to identify the susceptibility or resilience of decisions to social influence in a population with highly heterogeneous mode preferences.

Recent policy studies mainly focused on the effects of economic instruments to stimulate the up-take of EVs (Berestenau & Shanjun, 2011; Diamond, 2009; Gallagher & Muehlegger, 2011; Higgins et al., 2012; Sallee, 2008; Shafiei et al., 2012). Our simulation model, however, is designed to evaluate the impact of a wide range of interventions on consumer transport mode decisions that go beyond pure monetary incentives. To illustrate the suitability of our model for policy analysis, we present three separate scenarios assessing the effectiveness of policy instruments to encourage consumers to adopt EVs. All these policies are currently a matter of debate in Germany. The scenarios comprised (a) the establishment of a zero-emission-zone in Berlin, allowing only EVs and other zero emission vehicles to operate in a certain area of the city (*Zero-emission-zone* scenario), (b) the exemption of EVs from motor tax (*Tax exemption* scenario) and (c) the direct subsidy (in the amount of € 5000) towards the purchase of an EV (*Purchase subsidy* scenario). In contrast to the *Reference case*, agents' mental representations and subsequent decisions were not only affected by word of mouth in their social network, but agents moreover considered the consequences of policy measures in decision making. Corresponding to social influence, we therefore assumed that agents' belief-action representations (i.e. facilitation weights between needs and actions units) are modified by the influence of policy-related information in a specific manner for each intervention. To simulate repeated mass media campaigns, we transmitted in all scenarios information about the policies in every tenth time step (i.e. time step 0, 10, 20, 30 etc.) to 70% of the agent population by means of the media agent described above (section 2.4). After receiving this information, all agents reevaluated their transport mode decisions and carried on with the usual dyadic communication.

In the *Zero-emission-zone* scenario we conjecture –in accordance with empirical findings (Wolf et al., forthcoming) – that users would perceive higher levels of independence (i.e., flexibility by being allowed to enter all areas of the city) and a decrease in their stress-level caused by less traffic volume. In the logic of our parallel constraint network model (see Fig. 1), the information about this policy increases the facilitation relations between the needs of "independence" and "no stress" and the action "use EVs". Importantly, the additive changes of individual agent facilitation weights were multiplied by an empirically determined factor of policy impact (for details see section 2.4 and the appendix).

In both the *Tax exemption* and the *Purchase subsidy* scenarios we modeled the effects of fiscal incentives on widespread acceptance of EVs. Even though these policies affect different aspects of total cost of ownership of EVs -namely purchase versus operating costs- both equally cause in our model a positive shift of facilitation relations between the need of "cost efficiency" and the action "use EVs". In other words, agents believe due to the introduction of these policies that EVs accomplish their need of a cost efficient means of transport to a greater extent. These assumption are supported by empirical evidence showing that consumers do consider different financial benefits associated with alternative fuel vehicles in their adoption decisions (Chandra, Gulati, & Kandlikar, 2010; Diamond, 2009; Rogan, Dennehy, Daly, Howley, & Ó Gallachóir, 2011; Ryan, Ferreira, & Convery, 2009; Sallee, 2008), but are less accurate in distinguishing and estimating the actual economic value of these instruments (cf. Greene, 2010; Larrick & Soll, 2008; Turrentine & Kurani, 2007). Analogous to the *Zero-emission zone* scenario the individual impact of the two policies measures were weighted (i.e. multiplied) differently based on empirical appraisal ratings or our survey participants (e.g. "Would this policy measures change your attitude toward EVs?"). The two scenarios thus have the same structural effect on the agents' belief networks, but they differ in the quantitative strength of this effect.

Simulation results

In this section, we examine the results of simulating transport mode choices under the different scenarios. First, we discuss the reference case – the dynamics of transport mode preferences through communication among agents alone, without external intervention. Second, we evaluate policies promoting the diffusion of EVs relative to adoption trends in the base case. In both subsections we use the percentage of agents who prefer a particular mode of transport as a measure of impact –we refer to these agents as the "fraction of potential adopters". Recall that preferences are dynamically constructed based on pre-existing mental representations of agents and potentially changed through communication with other agents. These preferences may be interpreted as a mental preparedness to adopt a certain mode of transport. Thus, scenario results should not be interpreted as immediate market predictions, but rather as an explorative approach to investigate the resilience of current mental representations and travel behaviors to external influences.

Reference case scenario

The *reference case* scenario captures the influence of social communication on changes in individual travel choices of agents over time, without external intervention. Fig. 4 shows the proportion of users of five transport modes over time, averaged over 10 model runs and separately for the four consumer types described in section 2.1. Overall, preferences in the heterogeneous agent population remain relatively stable over the 100 time steps and exhibit low fluctuations. The modal split remains substantially different between the different types of travellers. In the group of *Comfort-oriented Individualists* (Fig. 4a) the use of combustion engine (ICE) cars continues to dominate travel choices, with initial shares at t_1 of 91% and of 89% by iteration 100. The graphs representing alternative modes indicate that EVs (form $t_1 = 3\%$ to $t_{100} = 4\%$), car sharing (from $t_1 = 1\%$ to $t_{100} = 1\%$), public transport (from $t_1 = 5\%$ to $t_{100} = 5\%$) and bicycles (from $t_1 = 0\%$ to $t_{100} = 1\%$) cannot compete with ICE cars in this segment. For the *Cost-oriented Pragmatics* (Fig. 4b) public transport continues to be the most attractive travel mode (36%), followed by bicycles with a slightly decreasing share from 27% (t_1) to 23% (t_{100}) and a constant subgroup of agents (25%) that favors the use of ICE cars. Although starting from a low level, the preferences for car sharing and EVs increase considerably in this segment by 100% (from $t_1 = 5\%$ to $t_{100} = 10\%$) and 60% (from $t_1 = 5\%$ to $t_{100} = 8\%$), respectively. *Innovation-oriented Progressives* (Fig. 4c) exhibit a slight decrease in their dominant shares of ICE cars (from $t_1 = 49\%$ to $t_{100} = 43\%$) and EVs (from $t_1 = 25\%$ to $t_{100} = 24\%$). The simulations show an inverted trend for agents' preferences in this traveller group related to public transport (increase from $t_1 = 15\%$ to $t_{100} = 17\%$) and car sharing (increase from $t_1 = 2\%$ to $t_{100} = 8\%$). As Fig. 4d illustrates, the almost equally distributed shares of bicycles (27%), public transport (28%) and EV (29%) users in the segment of the *Eco-oriented Opinion leaders* slightly diminish in favor of car sharing (from $t_1 = 8\%$ to $t_{100} = 14\%$) and ICE cars (from $t_1 = 7\%$ to $t_{100} = 8\%$).

To sum up, the simulation results indicate that social communication among peers alone causes at most marginal choice shifts in all the four consumer groups. Agents show a high resilience of their overall transport mode decisions, yet a few travelers exhibit the propensity to switch from car use to alternative travel modes (Fig. 4a and Fig. 4b). Interestingly, while car sharing accounts at the beginning of the simulation only for a very low overall share (between 0% and 8%), we observed the most considerable changes of all with regard to this mode option across three groups (Fig. 4b-d). This behavior of our model is consistent with a recently observed surge in the use of car sharing in the city of Berlin (Bock et al., 2013).

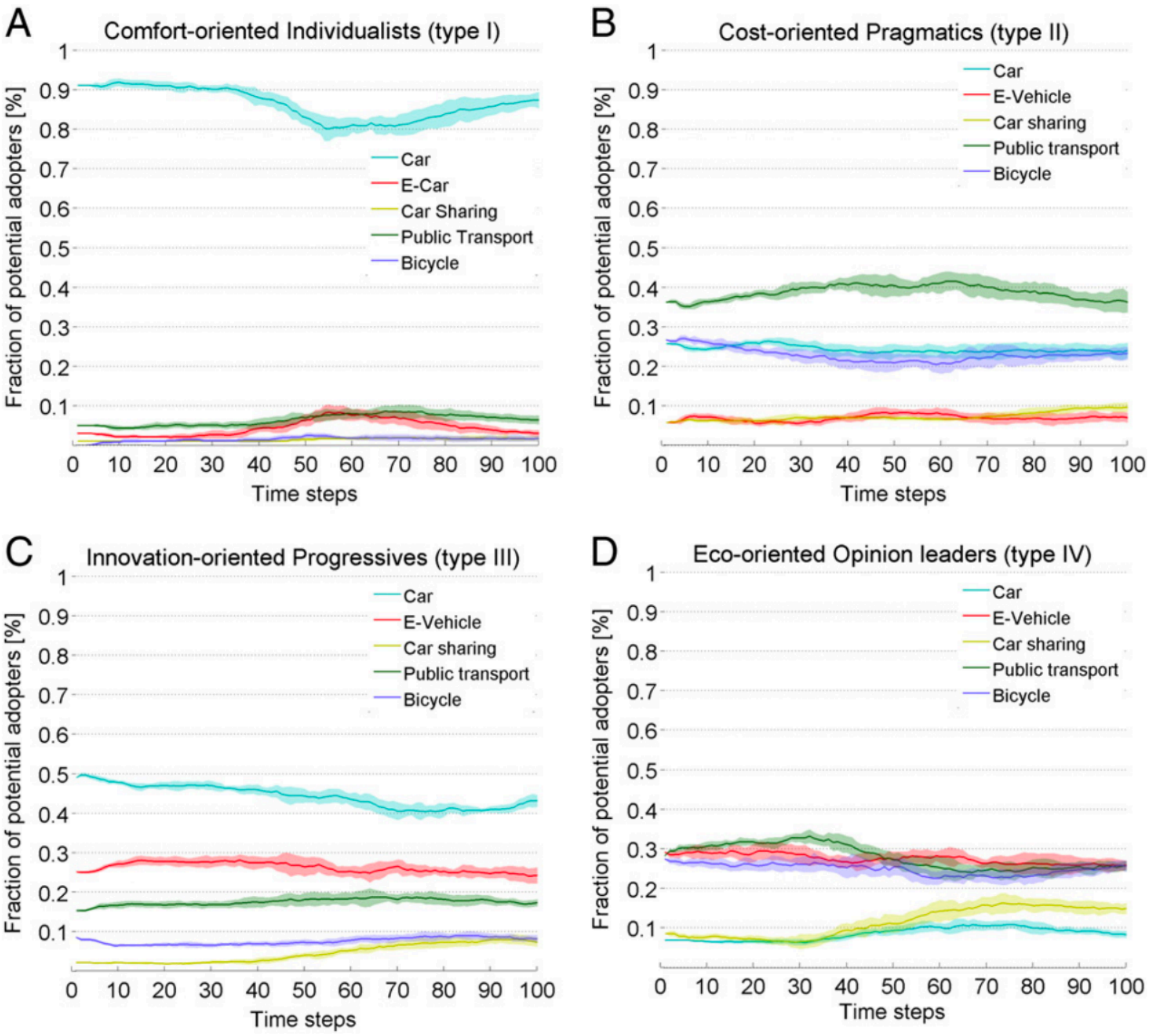

Figure 8. Diffusion of preferred modes of transport

Modal split over time of (a) Comfort-oriented Individualist (mobility type I), (b) Cost-oriented Pragmatics (mobility type II), (c) Innovation-oriented Progressives (mobility type III) and (d) Eco-oriented Opinion leaders (mobility type IV).

Electric-vehicle policy scenarios

The results of simulating three policy interventions, designed to accelerate the uptake of EVs, are depicted in Fig. 5 along with the potential adoption rates of EVs from the reference scenario for comparison. Quite plausibly, the simulations suggest that the four consumer types will respond differently to the policy measures (see Fig. 5a-d). *Comfort-oriented Individualists* (Fig. 5a) –the segment exhibiting the lowest EV acceptance rate in the reference case scenario– show increased propensity to adopt EVs in all policy simulations. Nevertheless, ICEs cars still dominate the modal share (between 74% to 77%) in this consumer group. The introduction of the zero-emission-zone leads to a temporary gradual increase of potential EV users, followed by a slight drop (compared to reference case at t_{100} = +13%) below the EV share in the *Purchase subsidy* scenario (+16%) and the *Tax exemption* scenario (+13%).

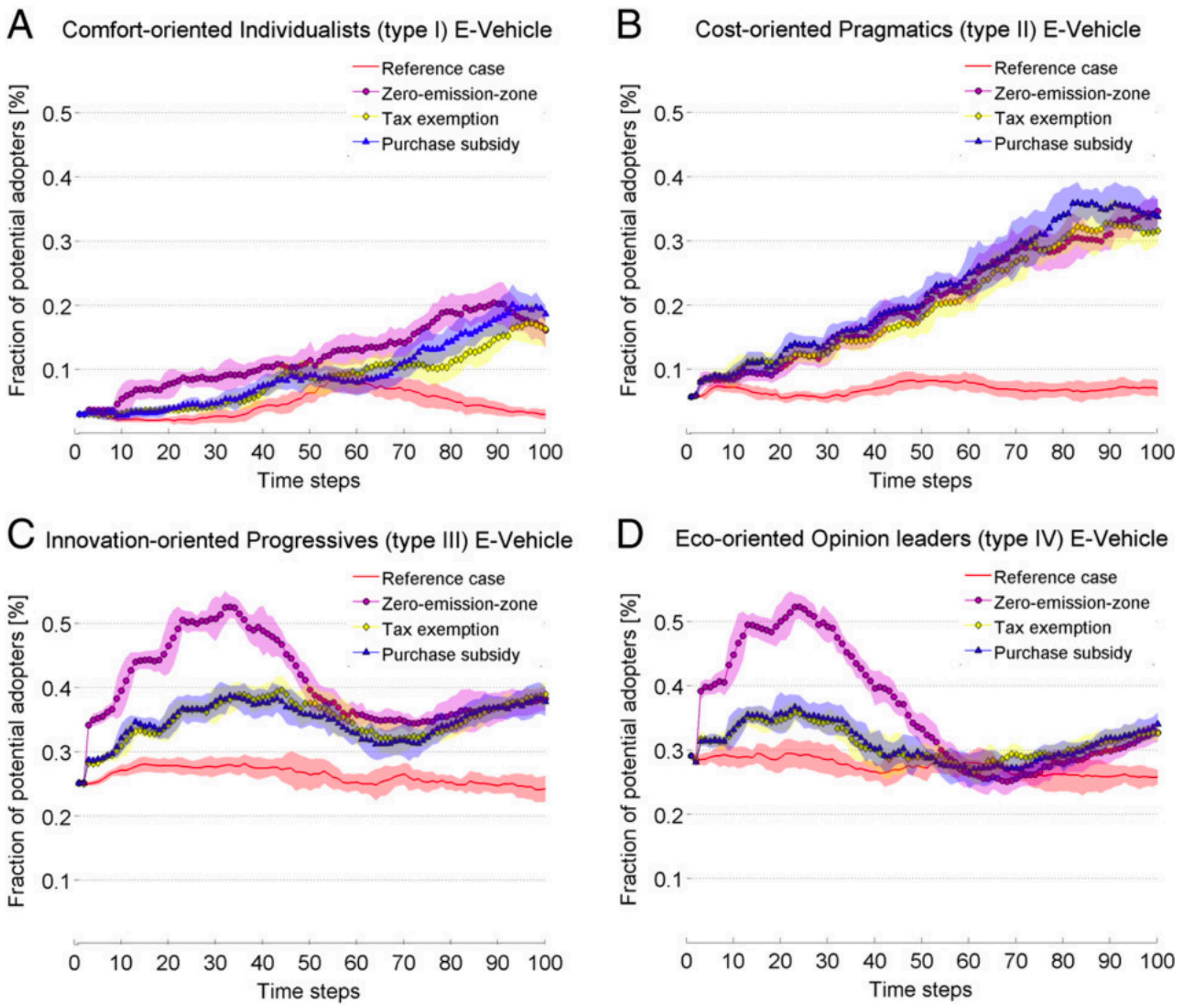

Figure 9. Diffusion of E-Vehicles in Reference case, Zero-emission-zone, Tax exemption and Purchase subsidy scenarios separated by clusters

Panel (a) presents the fraction of potential adopters for Comfort-oriented Individualist (mobility type I), panel (b) for Cost-oriented Pragmatics (mobility type II), panel (c) for Innovationoriented Progressives (mobility type III) and panel (d) for Eco-oriented Opinion leaders (mobility type IV).

Simulations suggest that the most significant changes triggered by policy measures in the modal share of EVs are to be expected in the sub-population of *Cost-oriented Pragmatics* (Fig. 5b). Both monetary policies increased the fraction of potential EV adopters linearly about 4.9-fold (up to a 34% share) in the *Purchase subsidy* scenario and about 4.4-fold (up to a 31% share) in the *Tax exemptions* scenario. Thereby the purchase subsidy intervention accelerated the acceptance most effectively almost throughout the whole simulated diffusion process. The introduction of a zero-emission-zone resulted in a 5.0-fold (up to 35% share) increase in EV use and thus showed the strongest effect compared to the reference case. The diffusion of EVs in the three policy scenarios comes about as a mode shift predominantly away from public transport (≈ -24%), bicycle (≈ -20%) and ICE cars (≈ -16%).

Fig. 5c and 5d illustrate a high level of fluctuation in EV shares across the simulated policies for the mobility types *Innovation-oriented Progressives* (Fig. 5c) and *Eco-oriented Opinion leaders* (Fig. 5d). Agents of these segments already show relative high acceptance rates of EVs to start with (25% of type III and 29% of type IV). The steep increase of the fraction of potential EV adopters in the *Zero-emission-zone scenario* up to 53% (type III) and 52% (type IV) indicates both that (i) a considerable number of agents in both traveler groups have a tendency to switch their current mode towards EVs and (ii) excluding ICE cars from certain urban areas leads to the most pronounced preference changes in any of the simulated scenarios. However, the following drop demonstrates that neither restrictive nor incentive policies are able to generate sustainable long-term preferences towards EVs at the peak level in these consumer groups. This indicates that consumers potentially willing to adopt EVs rethink their decisions in the light of alternative options. Triggered by the discussion with their social peers, they switch back to modes of transport, which are more commonly known and accepted. The zero-emission-zone policy resulted in final EV preference increases of 14% and 7% for *Innovation-oriented Progressives* (Fig. 5c) and *Eco-oriented Opinion leaders* (Fig. 5d), respectively, when compared to baseline. Tax exemption and purchase subsidy yielded up to 15% and 14% increase, respectively, in agents of type III, and 7% and 9% increase in agents of type IV. Mode shift in consumer type III mainly happened from the dominant ICE cars to EVs. In contrast, agents of mobility type IV reduced their preferences for the use of public transport and bicycle in favor of EVs, suggesting an ironic effect to a less sustainable form of transport choice in this consumer population. The variation of these fluctuation patterns across the four traveller groups shows that they are strongly constrained by the pre-existing mental representations and the following learning processes of agents in the simulation. The modeled policies are compatible with the consumer groups' initial representations to different degrees. Therefore, preference rates as well as their fluctuation differ across the scenarios.

Taken together, our simulation results contribute to current, political discussions about the anticipated consumer acceptance of EVs and about appropriate policy instruments to promote EVs. As shown in Fig. 6, the aggregated results across all agents yield optimistic projections for the acceptance of EVs under alternate sets of scenarios. In the reference case, EVs account for 15% of the total modal share. Simulations indicate that despite a considerably stable fraction of "early adopters" of EVs, social influence alone cannot effectively increase the spread of this innovation. Additional policy interventions are necessary to encourage a broader market penetration of EVs. The effects of simulated policy measures suggest a significant increase of potential adopters, with adoption rates converging over time up to 31% in the *Purchase subsidy*, 30% in *Zero-emission-zone* and 29% in *Tax exemption* scenario. Moreover, the results highlight in particular in short- and medium-term –indicated by the growth rate in the *Zero-emission-zone* scenario– the role of non-financial policy strategies for effective behavior change towards the adoption of EVs.

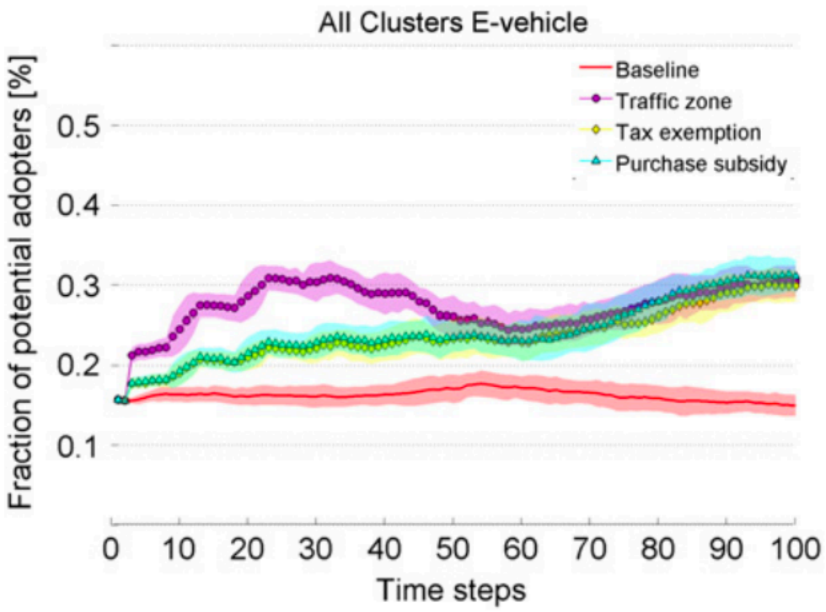

Figure 10. Diffusion of E-Vehicles in Reference case, Zero-emission-zone, Tax exemption and Purchase subsidy

Conclusions

We started with the premise that more psychologically realistic models of human decision-making are needed in innovation-diffusion simulations, in order to enhance their usefulness to political decision-makers and other practitioners. To address this need, we introduced a novel agent-based model (ABM), *InnoMIND* (*Inno*vation diffusion driven by changing *MIND*s), based on state-of-the-art theories in cognitive science and grounded in empirical data.

We employed this framework to analyze three what-if scenarios representing different policy interventions–tax exemption, purchase subsidy and the introduction of an exclusive zone for EVs–intended to promote the adoption preference of electric vehicles (EVs). Our simulation results have three main implications. First, the failure to consider heterogeneous needs of different travellers reduces the effectiveness of the policies modeled in this paper in a significant manner. Second, somehow unexpectedly, the introduction of an exclusive zone for EVs in the city is in particular in the early phase of the diffusion process of EVs more effective than financial incentives only. This result emphasizes the importance to address non-monetary considerations of consumers in the development of policy measures. Third, mode switches to EVs induced by policies in consumer groups currently using bicycles as their main mode of transportation might, quite ironically, counteract the goals of CO2 emission reduction.

In an additional baseline scenario where preferences of agents were only influenced by the interaction with their social peers, we did not find considerable shifts in transport mode preferences. This baseline simulation also suggests a relatively high and stable preference rate for EVs at least in two traveller groups among Berlin residents without additional interventions. Thus, we may conclude that travellers do not substantially change their pre-existing transport mode decisions when they interact with their social environment under constant external conditions.

As demonstrated above, the *InnoMIND* framework offers the possibility to explore the emergent properties that result from rather complex individual decisions under combined influence of social dynamics and policy measures. The model allows one to explore how current empirically-derived preferences might change dynamically as a result of social communication. Considering the pivotal role of decision-making processes in agent-based models, our proposed model provides a novel view on how beliefs, needs, priorities and emotions drive individual decisions about transport mode use. Complementary to research in social psychology that aims to understand the influence of motives and intentions on modal choices (Jillian Anable, 2005; Bergstad et al., 2011; Steg, 2005), our agent-based model provides a pathway for exploring the dynamical nature of these mental representations. Moreover, in contrast to economically rational decisions -assuming a serial deliberative analysis of risks and expected utilities of alternative actions- our approach conceives of decisions as a result of an automatic holistic process, accepting a transport option merely if it maximally satisfies the constraints given by mental representations.

We belief that this concept of the human mind in combination with our proposed segmentation approach may contribute to guiding the development of more demand-side oriented policy instruments considering emotional as well as cognitive constraints of behavioral change when attempting to encourage more sustainable transport choices.

Finally, the flexible nature of our policy simulation system allows the implementation of a broad range of policy scenarios. Although conceptualized and calibrated in this work to study the potential diffusion of EVs, the model may also be adopted to other issues of social transition with modest effort.

Limitations and directions of future work

Although we are convinced of the practical relevance of our simulation results for decision-makers in politics and business, our approach has limitations to be addressed in future work. First, the showcase region Berlin, Germany, on which we focused in this study, is not representative for the travel preferences and behavior of Germans (Infas et al., 2018). Specific characteristics of the city –such as the urban environment, low rates of car ownership, well-developed public transport, and the innovative brand of Berlin– necessarily limit the impact of reported simulation results on nation-wide policy interventions. However, our framework could be easily expanded to further regions or even across Germany. Provided the availability of suitable empirical data, a national model of diffusion of transport innovation could be used for exploring geographically tailored policy strategies, in order to achieve a transition to a low-carbon transport system in the country.

Second, the model ignores the supply side. A comprehensive assessment of EV diffusion, however, requires an integrative approach including technological, political and societal influence factors (Tran et al., 2012). Different electric-drive technologies such as full battery, plug-in hybrid, and fuel-cell EVs, as well as new business models, transport services, and marketing campaigns of manufacturers will have considerable impact on market dynamics. Due to the lack of sufficient data in the start-up phase of EV innovations, we were not able to ground supply-side actors similarly to consumers' decision motives. In future research, we intend to extend our model to account for technological innovations and marketing campaigns of manufacturers and other suppliers, based on empirical data.

Third, we did not explicitly model varying perceptions of short-term and long-term costs of vehicle ownership. A related body of literature in behavioral economics provides evidence that people tend to prefer immediate payoffs than more distant ones in time (e.g., Laibson, 1997). In consideration of higher purchase prices but lower cost of maintenance for EVs relative to internal combustion engine cars, this is an important issue. At present, little is known about how much consumers are willing to pay for future fuel savings (for review, see Greene, 2010). In the present work, we addressed these inconsistencies in part by subjective weights of impacts in the two monetary policy scenarios (see section 2.4). In future work, we plan to conduct behavioral experiments to even better inform our model empirically.

Despite these limitations, we believe that our agent-based model is a worthwhile research approach suitable for many further applications. Further activities could comprise the exploration of agency of households in transport innovation adoption or a more participative involvement of stakeholders (e.g., politicians or managers) in the modeling process (for review, see Barreteau et al., 2013).

Acknowledgements

This research was funded by the German Federal Ministry for Education and Research (BMBF) under grant #16|1610. Schröder's contributions were also supported by research fellowship #SCHR1282/1-1 from the German Research Foundation (DFG). We thank Paul Thagard for helpful discussions and comments on model development, Alexander Hatri for his contributions to programming the model in Java, Kerstin Stark and Jakob Dordevic for their assistance in data collection, and Jesse Hoey for valuable comments on an earlier version of the manuscript.

Appendix

Appendix A. Initial parameterization of agents

Table A1
Input and output parameter settings.

Variable type	Parameter	Range or value	Meaning	Input/ output
HOTCO parameter Need units (G_{1-8})	w_{ij}	−1 to +1	Facilitation weight between need unit and action unit ≙ cognitive representation to which degree a need is accomplished by a certain action	Input
	w_{ij}	−1 to +1	Valence weight between need unit and special valence unit ≙ valence of a specific need	Input
	p_i	−1 to +1	Priority weight between need unit and special unit ≙ priority of a need	Input
	a_i	−1 to +1	Activation of a need unit ≙ impact of a need on decision-making	Output
	v_i	−1 to +1	Valence of a need unit ≙ intrinsic emotional valence of a need or action	Output
Action units (A_{1-5})	w_{ij}	−1 to +1	Facilitation weight between need unit and action unit ≙ cognitive representation to which degree a need is accomplished by a certain action	Input
	w_{ij}	−1 to +1	Valence weight between action unit and special valence unit ≙ valence of a specific action	Input
	a_i	−1 to +1	Activation of an action unit ≙ indicates which option to choose	Output
	v_i	−1 to +1	Valence of an action unit ≙ emotional valence of the associated mode of transport	Output
Socio-demographic/-economic parameters	A	18 to 69	Age of an agent	Input
	G	0,1	Gender of an agent	Input
Further parameters	I	1 to 7	Income categories	Input
	E	1 to 5	Level of education	Input
	C	1 to 3.6	Standard of consumption[a]	Input
	M	1 to 4	Level of modernity[a]	Input
	T	1 to 4	Different mobility types based on previous conducted cluster analysis	Input
	r	0 to 1	Social radius ≙ social range of an agent limiting the size of the personal network	Input
	X,Y	0.33 to 0.68 0 to 1	Geographic coordinates (latitude and longitude) assigned to postal codes	Input
	μ		Weight of policy influence	Input

Note all input parameter are determined empirically based on our survey study. a = cf. Otte, G. (2005). Entwicklung und Test einer integrativen Typologie der Lebensführung für die Bundesrepublik Deutschland. Zeitschrift Für Soziologie, 34,
442–467.

Appendix B. Modeling persuasion in agent-to-agent communication

The percentage values shown in Tables B.1 and B.2 represent self-reported mean changes of opinions across subjects and transport

modes (N=480) as a result ofpositive and negative vignette statements using factual proposition (Table B.1) or emotional propositions (Table B.1). For instance, the first column in Table B.1 indicates that a listenerwith a very strong preference for EVs (wij ≥ .60) listening to a strong positive statement about EVs perceives a considerable enforcement ofthis belief(i.e. factor ofrational influence π=+8.3%). The influence of a negative statement, however, is for the same person almost negligible (i.e. factor of rational influence π=−0.3%).

Table B.1
Percentage factors of rational influence π for the information receiving agent in means–ends communication.

Senders' facilitation weight w_{ij}	Receivers"' facilitation weight w_{ij}				
	$w_{ij} \geq .60$	$.20 \leq w_{ij} < .60$	$-.20 \leq w_{ij} < .20$	$-.60 < w_{ij} < -.20$	$w_{ij} \leq -.60$
$w_{ij} > .30$	$\pi = +8.3\%$	$\pi = +7.3\%$	$\pi = +4.0\%$	$\pi = -4.1\%$	$\pi = -3.0\%$
$w_{ij} < -.30$	$\pi = -0.3\%$	$\pi = -0.6\%$	$\pi = -1.3\%$	$\pi = -0.3\%$	$\pi = -2.0\%$

Table B.2
Percentage factors of emotional influence α for the information receiving agent in contagion communication.

Senders' valence weight v_i	Receivers' valence weight v_{ij}				
	$v_i \geq .60$	$.20 \leq v_i < .60$	$-.20 \leq v_i < .20$	$-.60 < v_i < -.20$	$v_i \leq -.60$
$v_i > .10$	$\alpha = +7.5\%$	$\alpha = +3.5\%$	$\alpha = +0.6\%$	$\alpha = -1.0\%$	$\alpha = -2.5\%$
$v_i < -.10$	$\alpha = +4.0\%$	$\alpha = +0.35\%$	$\alpha = -0.1\%$	$\alpha = -0.85\%$	$\alpha = -1.8\%$

The content of communication is selective. Therefore the speaking agent selects based on a threshold (z) for facilitation weights (wij) z = ± 0.3 and for valences of actions (vi) z = ± 0.1, respectively, the content of the conversation.

Appendix C. The media agent

Table C1
Mean (M) policy impact factors and standard deviations (SD) of different mobility types.

	Type 1 Comfort-oriented Individualists		Type II Cost-Oriented Pragmatics		Type III Innovation-Oriented Progressives		Type IV Eco-Oriented Opinion Leaders	
	M	SD	M	SD	M	SD	M	SD
Policy impact factor for								
Zero-emission-zone scenario	.45	.25	.48	.22	.60	.20	.63	.21
Tax exemption scenario	.47	.26	.52	.27	.66	.22	.71	.22
Purchase subsidy scenario	.53	.28	.56	.26	.69	.23	.71	.23

Appendix D. Sensitivity analysis

We conduct a sensitivity analysis on the policy impact factor µusing five different parameter settings (µ= empirical/.25/.50/.75/ 1.00). We conducted one model runs for each simulation to assess the effect on the preferences for EVs across the hole agent population for each setting. We look at the effects on EV preferences at time step t =100.

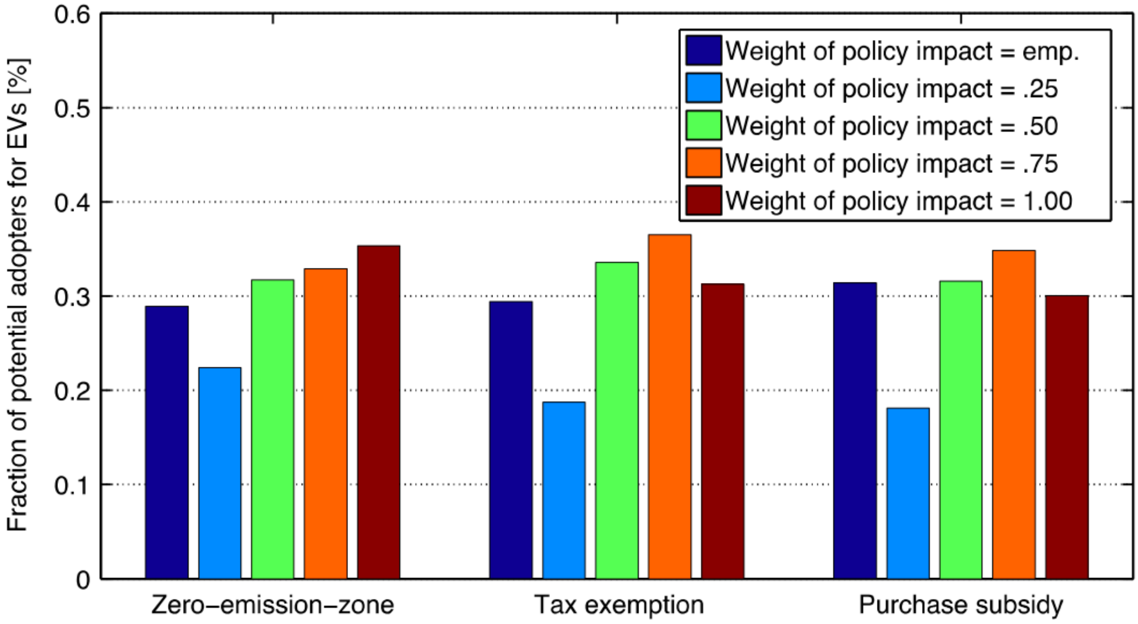

Fig. D1. Preferences for EVs at time step t = 100.

References

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, *50*, 179–211.

Al-Alawi, B. M., & Bradley, T. H. (2013). Review of hybrid, plug-in hybrid, and electric vehicle market modeling Studies. *Renewable and Sustainable Energy Reviews*, *21*, 190–203. doi:10.1016/j.rser.2012.12.048

Anable, J. (2005). "Complacent Car Addicts" or "Aspiring Environmentalists"? Identifying travel behaviour segments using attitude theory. *Transport Policy*, *12*(1), 65–78.

Aral, S., & Walker, D. (2012). Identifying influential and susceptible members of social networks. *Science (New York, N.Y.)*, *337*(6092), 337–41.

Armitage, C. J., & Conner, M. (2001). Efficacy of the Theory of Planned Behaviour: a meta-analytic review. *The British Journal of Social Psychology*, *40*(4), 471–99. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11795063

Axsen, J., & Kurani, K. S. (2011). Interpersonal influence in the early plug-in hybrid market: Observing social interactions with an exploratory multi-method approach. *Transportation Research Part D: Transport and Environment*, *16*(2), 150–159.

Axsen, J., & Kurani, K. S. (2012). Developing sustainability-oriented values: Insights from households in a trial of plug-in hybrid electric vehicles. *Global Environmental Change*, *null*(null). doi:10.1016/j.gloenvcha.2012.08.002

Bamberg, S. (2006). Is a Residential Relocation a Good Opportunity to Change People's Travel Behavior? Results From a Theory-Driven Intervention Study. *Environment and Behavior*, *38*(6), 820–840.

Barreteau, O., Bots, P., Daniell, K., Etienne, M., Perez, P., Barnaud, C., Trebuil, G. (2013). Participatory Approaches. In B. Edmonds & R. Meyer (Eds.), *Simulating social complexity - A Handbook* (pp. 197–234). Springer.

Bechtel, W., & Abrahamsen, A. (2002). *Connectionism and the Mind : Parallel Processing Dynamics and Evolution* (2 edition.). Oxford, England: Wiley-Blackwell.

Berestenau, A., & Shanjun, L. (2011). Gasonline Prices, Goverment Support, and the Demand for Hybrid Vehicles in the United States. *International Economic Review*, *52*(1), 161–182.

Bergstad, C. J., Gamble, A., Hagman, O., Polk, M., Gärling, T., & Olsson, L. E. (2011). Affective–symbolic and instrumental–independence psychological motives mediating effects of socio-demographic variables on daily car use. *Journal of Transport Geography*, *19*(1), 33–38.

Blau, P. M. (1977). *Inequality and Heterogeneity*. Free Press.

BMVBS, & DLR. (2008). *MiD-2008 - „Mobilität in Deutschland"*. Publication through http://www.clearingstelle-verkehr.de hosted by DLR Institut für Verkehrsforschung.

Bonabeau, E. (2002). Agent-based modeling: methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences of the United States of America*, *99 Suppl 3*(90003), 7280–7.

Brown, M. (2013). Catching the PHEVer: Simulating Electric Vehicle Diffusion with an Agent-Based Mixed Logit Model of Vehicle Choice. *Journal of Artificial Societies and Social Simulation*, *16*(2), 5.

Castellano, C., Fortunato, S., & Loreto, V. (2009). Statistical physics of social dynamics. *Rev. Mod. Phys.*, *81*(2), 591–646. doi:10.1103/RevModPhys.81.591

Chaiken, S. (1987). The heuristic model of persuasion. In M. P. Zanna, J. M. Olson, & C. P. Herman (Eds.), *Social influence: The Ontario Symposium* (p. Vol. 5, pp. 3–39). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Chandra, A., Gulati, S., & Kandlikar, M. (2010). Green drivers or free riders? An analysis of tax rebates for hybrid vehicles. *Journal of Environmental Economics and Management*, *60*(2), 78–93.

Chen, S., & Chaiken, S. (1999). The heuristic-systematic model in its broader context. In S. Chaiken & Y. Trope (Eds.), *Dual-process theories in social psychology* (pp. 73–96). New York, NY, US: Guilford Press.

Collins, C. M. (2005). Psychological and Situational Influences on Commuter-Transport-Mode Choice. *Environment and Behavior*, *37*(5), 640–661.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Putnam Publishing.

Deffuant, G. (2006). Comparing Extremism Propagation Patterns in Continuous Opinion Models. *Journal of Artificial Societies and Social Simulation*, *9*(3). Retrieved from http://jasss.soc.surrey.ac.uk/9/3/8.html

Deffuant, G., Neau, D., Amblard, F., & Weisbuch, G. (2000). Mixing beliefs among interacting agents. *Advances in Complex Systems*, *03*(01n04), 87–98. doi:10.1142/S0219525900000078

Deutsch, R., & Strack, F. (2006). Duality Models in Social Psychology: From Dual Processes to Interacting Systems. *Psychological Inquiry*, *17*(3), 166–172.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy*, *37*(3), 972–983.

Edmonds, B. (2006). How are physical and social spaces related? In F. C. Billari, T. Fent, A. Prskawetz, & J. Scheffran (Eds.), *Agent-Based Computational Modelling*. Springer.

Egbue, O., & Long, S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy*, *48*, 717–729.

Eppstein, M. J., Grover, D. K., Marshall, J. S., & Rizzo, D. M. (2011). An agent-based model to study market penetration of plug-in hybrid electric vehicles. *Energy Policy*, *39*(6), 3789–3802.

Epstein, J. M., & Axtell, R. L. (1996). *Growing Artificial Societies: Social Science from the Bottom Up* (p. 224). Cambridge, MA: MIT Press.

Faber, A., Valente, M., & Janssen, P. (2010). Exploring domestic micro-cogeneration in the Netherlands: An agent-based demand model for technology diffusion. *Energy Policy*, *38*(6), 2763–2775. doi:10.1016/j.enpol.2010.01.008

Fishbein, M., & Ajzen, I. (2010). *Predicting and changing behavior: The reasoned action approach*. New York: Psychology Press (Taylor & Francis).

Fujii, S. (2007). Communication with non-drivers for promoting long-term pro-environmental travel behaviour. *Transportation Research Part D: Transport and Environment*, *12*(2), 99–102.

Gallagher, K. S., & Muehlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *Journal of Environmental Economics and Management*, *61*(1), 1–15.

Gigerenzer, G., & Goldstein, D. G. (1996). Reasoning the fast and frugal way: models of bounded rationality. *Psychological Review*, *103*(4), 650–69.

Graham-Rowe, E., Skippon, S., Gardner, B., & Abraham, C. (2011). Can we reduce car use and, if so, how? A review of available evidence. *Transportation Research Part A: Policy and Practice*, *45*(5), 401–418.

Greene, D. (2010). *How Consumers Value Fuel Economy : A Literature Review How Consumers Value Fuel Economy* (p. EPA–420–R–10–008). Washington, DC.

Hamill, L., & Gilbert, N. (2009). Social Circles: A Simple Structure for Agent-Based Social Network Models. *Journal of Artificial Societies and Social Simulation*, *12*(2).

Hatfield, E., Cacioppo, J. T., & Rapson, R. L. (1993). Emotional Contagion. *Current Directions in Psychological Science*, *2*(3), 96–99.

Hegselmann, R., & Krause, U. (2002). Opinion Dynamics and Bounded Confidence Models: Analysis and Simulation. *Journal of Artificial Societies and Social Simulation, 5(3).*

Helbing, D. (Ed. . (2012). *Social Self-Organization - Agent-Based Simulations and Experiments to Study Emergent Social Behavior* (p. 340). Springer-Verlag, Berlin.

Higgins, A., Paevere, P., Gardner, J., & Quezada, G. (2012). Combining choice modelling and multi-criteria analysis for technology diffusion: An application to the uptake of electric vehicles. *Technological Forecasting and Social Change*.

Homer-Dixon, T., Leader Maynard, J., Mildenberger, M., Milkoreit, M., Mock, S. J., Quilley, S., … Thagard, P. (2013). A complex systems approach to the study of ideology: Cognitive-affective structures and the dynamics of belief change. *Journal of Social and Political Psychology*, *1*(1). doi:10.5964/jspp.v1i1.36

Hunecke, M., Blobaum, A., Matthies, E., & Hoger, R. (2001). Responsibility and Environment: Ecological Norm Orientation and External Factors in the Domain of Travel Mode Choice Behavior. *Environment and Behavior*, *33*(6), 830–852.

Iyengar, R., Van den Bulte, C., & Valente, T. W. (2010). Opinion Leadership and Social Contagion in New Product Diffusion. *Marketing Science*, *30*(2), 195–212.

Jager, W., Janssen, M. A., Vries, H. J. M. De, Greef, J. De, & Vlek, C. A. J. (2000). Behaviour in commons dilemmas: Homo economicus and Homo psychologicus in an ecological-economic model. *Ecological Economics*, *35*(3), 357–379.

Kahnemann, D. (2011). *Thinking, fast and slow*. New York: Farrar, Straus and Giroux.

Kemp, R., & J., R. (2004). Managing the transition to sustainalbe mobility. In *System Innovation and the Transition to Sustainability* (pp. 137–167). Cheltenham, UK: Edward Elgar Publishing Ltd.

Kiesling, E., Günther, M., Stummer, C., & Wakolbinger, L. M. (2011). Agent-based simulation of innovation diffusion: a review. *Central European Journal of Operations Research*, *20*(2), 183–230.

Klöckner, C. A., & Blöbaum, A. (2010). A comprehensive action determination model: Toward a broader understanding of ecological behaviour using the example of travel mode choice. *Journal of Environmental Psychology*, *30*(4), 574–586.

Köhler, J., Whitmarsh, L., Nykvist, B., Schilperoord, M., Bergman, N., & Haxeltine, A. (2009). A transitions model for sustainable mobility. *Ecological Economics*, *68*(12), 2985–2995.

Kunda, Z. (1990). The case for motivated reasoning. *Psychological Bulletin*, *108*, 480–498.

Laibson, D. (1997). Golden eggs and hyperbolic discounting. *The Quarterly Journal of Economics*, *112*(2), 443–478.

Larrick, R. P., & Soll, J. B. (2008). The MPG Illusion. *Science (New York, N.Y.)*, *320*(June).

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin*, *127*(2), 267–286.

Mcpherson, M., Smith-lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in Social Networks. *Annual Review of Sociology*, *27*, 415–444.

Mehrabian, A., & Wetter, R. de. (1987). Experimantal test of an emotion-based approach to fitting brad names to products. *Journal of Applied Psychology*, *72(1)*, 125–130.

Monroe, B. M., & Read, S. J. (2008). A general connectionist model of attitude structure and change: the ACS (Attitudes as Constraint Satisfaction) model. *Psychological Review*, *115*(3), 733–59.

NPE, N. P. E. (2012). *Fortschrittsbericht der Nationalen Plattform Elektromobilitaet (Dritter Bericht)*. Berlin.

Nykvist, B., & Whitmarsh, L. (2008). A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting and Social Change*, *75*(9), 1373–1387.

Osgood, C. E., & Tannenbaum, P. H. (1955). The principle of congruity in the prediction of attitude change. *Psychological Review*, *62*(1), 42–55.

Ozaki, R., & Sevastyanova, K. (2011). Going hybrid: An analysis of consumer purchase motivations. *Energy Policy*, *39*(5), 2217–2227.

Petty, R. E., & Cacioppo, J. T. (1986). *Communication and persuasion: Central and peripheral routes to attitude change*. New York: Springer-Verlag.

Read, S. J., & Urada, D. I. (2003). A neural network simulation of the outgroup homogeneity effect. *Personality and Social Psychology Review : An Official Journal of the Society for Personality and Social Psychology, Inc*, *7*(2), 146–69.

Rogan, F., Dennehy, E., Daly, H., Howley, M., & Ó Gallachóir, B. P. (2011). Impacts of an emission based private car taxation policy – First year ex-post analysis. *Transportation Research Part A: Policy and Practice*, *45*(7), 583–597.

Ryan, L., Ferreira, S., & Convery, F. (2009). The impact of fiscal and other measures on new passenger car sales and CO2 emissions intensity: Evidence from Europe. *Energy Economics*, *31*(3), 365–374.

Sallee, J. (2008). *The incidence of tax credits for hybrid vehicles*. Harris School Working Paper Series 08, 16.

Schröder, T., Stewart, T. C., & Thagard, P. (2013). Intention, Emotion, and Action: A Neural Theory Based on Semantic Pointers. *Cognitive Science*, 1–30. doi:10.1111/cogs.12100

Schröder, T., & Thagard, P. (2011). Motivated cognition and emotional bias in politics: Why Guttenberg has stayed so popular. *Report Psychologie*, *36*(9), 358–368.

Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental , hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, *48*(October), 39–49.

Schwarz, N., & Ernst, A. (2009). Agent-based modeling of the diffusion of environmental innovations — An empirical approach. *Technological Forecasting and Social Change*, *76*(4), 497–511. doi:10.1016/j.techfore.2008.03.024

Senate administration of Berlin for urban development. (2010). *Mobilität der Stadt – Berliner Verkehr in Zahlen*. Berlin.

Shafiei, E., Thorkelsson, H., Ásgeirsson, E. I., Davidsdottir, B., Raberto, M., & Stefansson, H. (2012). An agent-based modeling approach to predict the evolution of market share of electric vehicles: A case study from Iceland. *Technological Forecasting and Social Change*, *79*(9), 1638–1653.

Sobkowicz, P. (2009). Modelling Opinion Formation with Physics Tools : Call for Closer Link with Reality. *Journal of Artificial Societies and Social Simulation*, *12*(1).

Sobkowicz, P., Kaschesky, M., & Bouchard, G. (2012). Opinion mining in social media: Modeling, simulating, and forecasting political opinions in the web. *Government Information Quarterly*, *29*(4), 470–479. doi:10.1016/j.giq.2012.06.005

Squazzoni, F., Jager, W., & Edmonds, B. (2013). Social Simulation in the Social Sciences: A Brief Overview. *Social Science Computer Review*. doi:10.1177/0894439313512975

Steg, L. (2005). Car use: lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice*, *39*(2-3), 147–162.

Sullivan, J. L., Salmeen, I. T., & Simon, C. P. (2009). *PHEV marketplace penetration: An agent based simulation*. University of Michigan, Ann Arbor, Transportation Research Institute.

Sun, R. (2012). *Grounding social sciences in cognitive sciences*. MIT Press.

Thagard, P. (2000). *Coherence in thought and action*. Cambridge, MA: MIT Press.

Thagard, P. (2003). Why wasn't O.J. convicted? Emotional coherence in legal inference. *Cognition & Emotion*, *17*(3), 361–383.

Thagard, P. (2006). *Hot thought: Mechanisms and applications of emotional cognition*. Cambridge, MA: MIT Press.

Thagard, P., & Kroon, F. W. (2006). Emotional consensus in group decision making. *Mind & Society*, *5*(1), 85–104.

Thagard, P., & Millgram, E. (1995). Inference to the best plan: A coherence theory of decision. In A. Ram & D. B. Leake (Eds.), *Goal-driven learning* (pp. pp. 439–454). Cambridge, MA: MIT Press.

Tran, M. (2012a). Agent-behaviour and network influence on energy innovation diffusion. *Communications in Nonlinear Science and Numerical Simulation*, *17*(9), 3682–3695.

Tran, M. (2012b). Technology-behavioural modelling of energy innovation diffusion in the UK. *Applied Energy*, *95*, 1–11.

Tran, M., Banister, D., Bishop, J. D. K., & McCulloch, M. D. (2012). Realizing the electric-vehicle revolution. *Nature Climate Change*, *2*(5), 328–333.

Turrentine, T. S., & Kurani, K. S. (2007). Car buyers and fuel economy? *Energy Policy*, *35*(2), 1213–1223.

Valente, T. W. (1995). *Network models of the diffusion of innovations*. Cresskill, NJ: Hampton Press.

Valente, T. W. (2005). Network Models and Methods for Studying the Diffusion of Innovations. In P. Carrington, J. Scott, & S. Wasserman (Eds.), *Models and Methods in Social Network Analysis* (pp. 98–116). New York, New York: Cambridge University Press.

Van der Werff, E., Steg, L., & Keizer, K. (2013). The value of environmental self-identity: The relationship between biospheric values, environmental self-identity and environmental preferences, intentions and behaviour. *Journal of Environmental Psychology*, *34*(null), 55–63.

Van Overwalle, F., & Siebler, F. (2005). A connectionist model of attitude formation and change. *Personality and Social Psychology Review*, *9*(3), 231–74.

Wolf, I., Hatri, A., Schröder, T., Neumann, J., & de Haan, G. (n.d.). Two faces of persuasion: An experimental and modeling approach of coherence effect. *Journal of Experimental Social Psychology*.

Wolf, I., Schröder, T., Neumann, J., Hoffmann, C., & de Haan, G. (n.d.). Emotions, self and electric vehicles: Towards a emotion-based travel behavior market segmentation. *Journal of Consumer Research*.

Zhang, T., Gensler, S., & Garcia, R. (2011). A Study of the Diffusion of Alternative Fuel Vehicles: An Agent-Based Modeling Approach. *Journal of Product Innovation Management*, *28*(2), 152–168.

Zhang, T., & Nuttall, W. J. (2011). Evaluating Government's Policies on Promoting Smart Metering Diffusion in Retail Electricity Markets via Agent-Based Simulation*. *Journal of Product Innovation Management*, *28*(2), 169–186. doi:10.1111/j.1540-5885.2011.00790.x

Zhang, X., Wang, K., Hao, Y., Fan, J.-L., & Wei, Y.-M. (2013). The impact of government policy on preference for NEVs: The evidence from China. *Energy Policy*, *61*, 382–393. doi:10.1016/j.enpol.2013.06.114

8 Studie 4 – Makrobene: Modeling multi-level mechanisms of environmental attitudes and behaviours: The example of carsharing in Berlin

Veröffentlicht als:

Schröder, T., & Wolf, I. (2017). Modeling multi-level mechanisms of environmental attitudes and behaviours: The example of carsharing in Berlin. *Journal of Environmental Psychology*, *52*, 136–148. https://doi.org/10.1016/j.jenvp.2016.03.007

Abstract

Psychological research practices are often prone to individualistic biases, emphasizing individual-level mechanisms of attitudes, behaviour, and persuasion, while neglecting the dynamics of communication in social networks. We illustrate with our InnoMind simulation model how agent-based modeling as a research method can account for the multi-level interactions between information processing in individual brains and flows of information in societies. InnoMind is based on theories of emotional cognition from cognitive science, theories of attitudes and persuasion from social psychology, and theories of social networks from sociology. In a case study, we show how the model can be used to address practical research questions in environmental psychology: We describe computer simulations with InnoMind that can serve as ex-ante evaluations of suitable campaign strategies for the promotion of carsharing as an innovative means of sustainable urban transportation. We discuss how empirical/experimental versus computational/theoretical research strategies in environmental psychology can and should be regarded as mutually informative.

Keywords

Attitudes, Environmental Behaviour, Agent-based Model, Innovation, Carsharing

Introduction

An important topic of environmental psychology is the role of human decision-making and behaviour in sustainable development. Often, the goal of environmental psychologists is to come up with scientifically based strategies to change people's attitudes and behaviours in desirable ways – for example, to persuade commuters to use public transport instead of cars. A major limitation to this endeavour stems from the individualistic bias of psychology as a discipline: Psychological theories and research practices tend to neglect the fact that individual perceptions, decisions, and actions are always embedded in a larger social system (Oishi, Kesbir, & Snyder, 2009; Scholl, 2007). This individualistic bias sometimes leads to underestimating the complexity involved in changing people's attitudes and behaviours, as information processing in individual brains interacts with social dynamics and flows of information at the level of society (e.g., Homer-Dixon, Leader Maynard, Mildenberger, Milkoreit, Mock, Quilley et al., 2013). Of course, many sociologists – and, more recently, physicists and computer scientists – have studied the social dynamics of changing attitudes and behaviours (e.g., Friedkin & Johnson, 1999; Pentland, 2014; Rogers, 2003), but they in turn tend to neglect the individual cognitive and emotional mechanisms underlying such changes. For developing effective strategies for attitude and behaviour change in support of a more sustainable society, environmental psychologists need tools that integrate knowledge about the relevant mechanisms across individual and social levels of explanation and across the scientific disciplines.

In this paper, we use our agent-based model InnoMind (for Innovation Diffusion by Changing Minds) (Wolf, Schröder, Neumann, & de Haan, 2015) as an example to demonstrate the suitability of social simulation as a method to analyze the multi-level mechanisms underlying environmental behaviour. The idea behind social simulation is to model artificial societies with computer programs that represent individual actors and their decision rationales as well as the communications among those actors (for review, see Helbing & Balietti, 2012; Squazzoni, Jager, & Edmonds, 2014; Epstein & Axtell, 1996). The InnoMind model was developed as a decision-support tool for policy-makers and other stakeholders in the context of the dissemination of electric cars (Wolf et al., 2015); however, we will show in the present paper that it is a generic multi-level model of attitudinal dynamics in a society that can be easily adapted to other research questions besides electric cars. InnoMind is rigorously based on psychological and sociological theory and informed by empirical data gained from classical social science research such as experiments and surveys. In the next section, we will describe how it works. Then, we provide the design of a media campaign purported to promote carsharing in cities as an example case study that illustrates the kinds of research questions that can be answered with theoretically plausible and empirically grounded simulation models.

The InnoMind Model

Here, we provide a summary description of the agent-based model InnoMind, whose development as well as a previous application simulating dissemination strategies for electric cars are described elsewhere (Wolf et al., 2015). We proceed here by levels of explanation. First, we illustrate how individual agents' attitudes are represented as constraint-satisfaction networks (Thagard, 2000; 2006). Second, we explain how attitude change as a result of agent-to-agent communication is modeled as a change in the topological structure of those networks. Third, we describe how InnoMind models flows of communication in society as an artificial social network implementing the principle of homophily established in sociology (McPherson, Smith-Lovin, & Cook, 2001). In each of these three subsections, we first describe the relevant theoretical background (i.e., attitudes, persuasion, social networks), then the computational implementation of the theory in InnoMind, and finally empirical strategies for connecting InnoMind simulations to psychological and sociological reality (cf. Sobkowicz, 2009). We keep the present description verbal to convey the basic ideas as simply as possible, but readers interested in the more technical details will find information on equations and parameters in the Appendix and in Wolf et al. (2015).

The Individual Level: Modeling Agents' Attitudes

InnoMind can be used to simulate attitude changes that result from the complex interactions of multiple agents. At the core of InnoMind is thus a model of individual agents' attitudes, which is based on relevant psychological theory and can be grounded in empirical data.

Theoretical background. From the perspective of psychology, attitudes are evaluative dispositions of individuals towards certain mentally represented objects, issues, or people (Fishbein & Ajzen, 2010; Petty & Briñol, 2015). Attitudes have cognitive, affective and conative aspects (Ajzen, 1989); i.e., the beliefs, feelings, and action tendencies, respectively, associated with an object. Attitudes can vary along a spectrum from more implicit, associative, and automatic to more explicit, propositional, and reflective evaluations (Fazio & Towles-Schwenn, 1999; Gawronski & Bodenhausen, 2007). Similarly, attitudes influence people's behaviours through a variety of mechanisms from more automatic ones that operate outside people's awareness (Bargh & Chartrand, 1999) to more controlled ones that operate through people's deliberate intentions (Fishbein & Ajzen, 2010).

From the perspective of cognitive-affective neuroscience, the different aspects of attitudes (beliefs, affect, implicit vs. explicit evaluations etc.) should, however, not be understood as separate categories, but rather as dynamically interacting components (Cunningham & Zelazo, 2007; Duncan & Barrett, 2007; Schröder, Stewart, & Thagard, 2014). The attitude-behaviour relationship can be described as a parallel constraintsatisfaction process, where many different – more or less conscious – mental representations such as beliefs, emotions, and intentions compete with each other interactively in the brain for control over behaviour (Ehret, Monroe, & Read, 2015; Monroe & Read, 2008; Orr, Thrush, & Plaut, 2013; Schröder et al., 2014; Schröder & Thagard, 2014). Based on Thagard's (2006) computational HOTCO model of emotional cognition (for HOT COgnition), InnoMind uses artificial neural networks to model individual attitudes as parallel constraint satisfaction.

Computational implementation. The HOTCO networks representing InnoMind agents are localist neural networks, signifying that their nodes represent single concepts, while the links between the nodes represent relationships between the concepts. At any given point in time, the nodes exhibit varying degrees of activation, which roughly corresponds to the current cognitive salience of the concepts represented by the nodes. There are two possible types of relationships in a localist network. Concepts can be mutually compatible (e.g., environmental friendliness and bikes), which is modeled by the spread of activation from one node to a connected node. Concepts can also be incompatible (e.g, environmental friendliness and old diesel cars), which is modeled by inhibition of the activation of connected nodes. In a localist network, which may represent many different concepts as well as compatibility and incompatibility relationships between them, updating the activation of nodes as a function of all their connections in several iterations often yields a stable network pattern, where some nodes are activated and some are inhibited. This iterated network-stabilization process is an efficient solution to parallel-constraint-satisfaction problems and was shown empirically to predict many instances of human decision-making (Glöckner & Betsch, 2008; Glöckner, Hilbig, & Jekel, 2014; McClelland, Mirman, Bolger, & Khaitan, 2014; Thagard, 2000).

Localist networks like HOTCO are not biologically realistic, as in the brain concepts do not correspond to single neurons, but rather to patterns of activity in large populations of neurons. However, it could be shown that the kinds of networks used to model InnoMind agents translate readily into more realistic neurocomputational models; hence, they can be regarded as viable approximations to the computations of real brains (Schröder & Thagard, 2014; Thagard & Aubie, 2008). Most importantly, HOTCO networks appropriately model the cognition-emotion interactions that underlie attitudes, decisions, and behaviours (Simon, Stenstrom, & Read, in press;

Thagard, 2006). Fig. 1(A) shows the generic architecture of an InnoMind agent. There are two layers of nodes that represent the agent's perceived needs2 and action options. A special valence node that is connected to the first layer of nodes (i.e. needs) is used to model emotional influences on the agent's attitudes (cf. Petty & Briñol, 2015). For example, people might have a need to see themselves as environmentally friendly and attach positive emotions to this need. They might also have a need to avoid stress, to which they attach negative emotions. Cognitive beliefs are modeled in InnoMind agents by excitatory and inhibitory links between need and action nodes. For example, if a person thinks that using public transport would be conducive to their need of environmental friendliness, InnoMind models this belief as an excitatory link between a need node that represents environmental friendliness and action node that represents the use of public transport. "Excitatory link" means that there is a spread of activation between the nodes; i.e., activation of the node representing environmental friendliness will spread to the node representing the use of public transport (and vice versa). Relatedly, a person might think that driving a car would contradict their need of environmental friendliness. InnoMind would model this belief as an inhibitory link between the two respective nodes; i.e., activation of the environmental friendliness node would suppress the activation of the car-driving node.

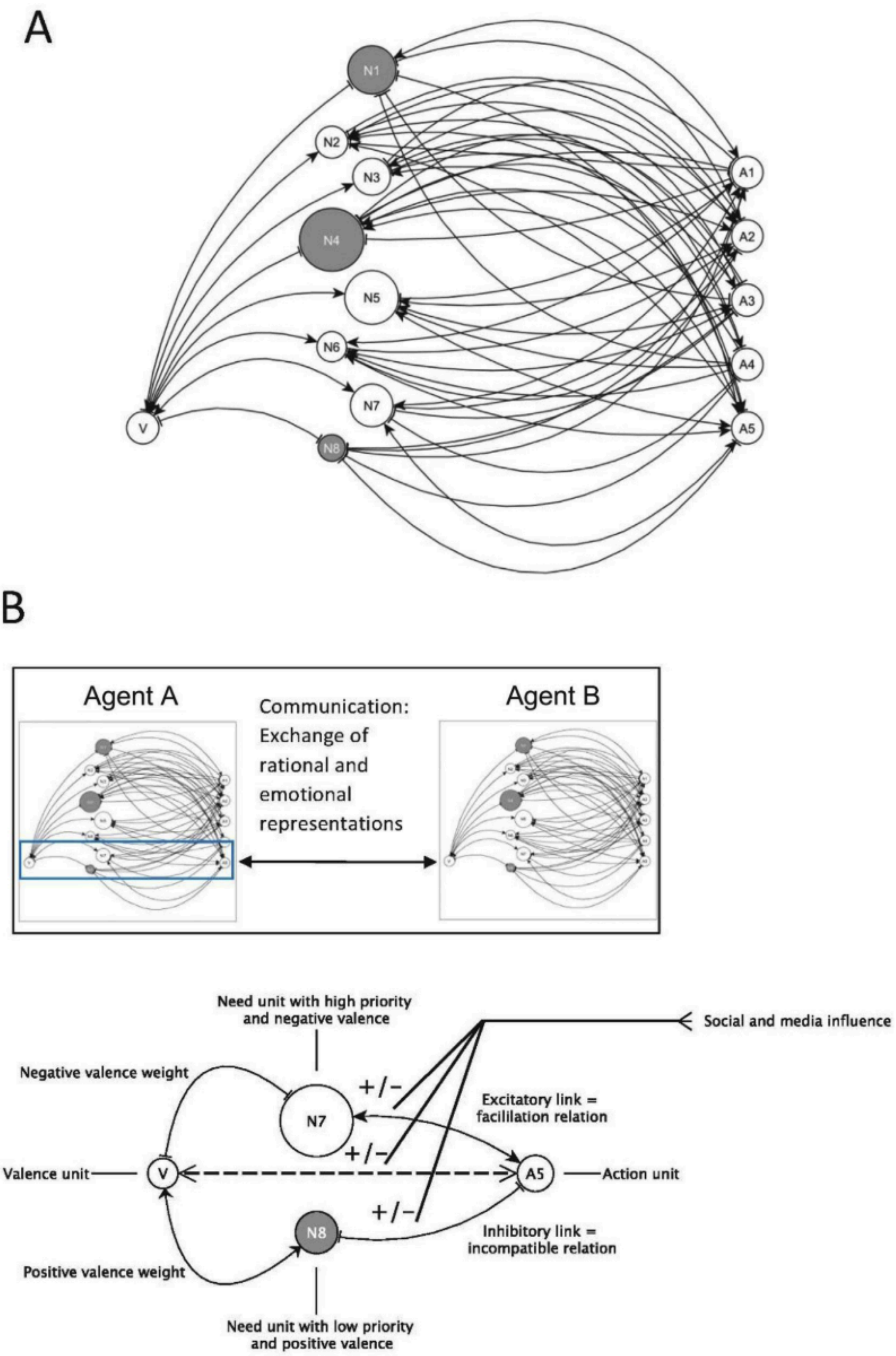

Figure 11. Connectionist InnoMind agent architecture

(A) Implementation of communication mechanisms between InnoMind agents (B). N=Need, V=Valence, A=Action.

Once all the needs and actions, along with their respective valences and interconnections, are defined, InnoMind computes for every agent a coherent set of attitudes towards the different action options by using a connectionist constraint-satisfaction algorithm (Thagard & Verbeurgt, 1998). The algorithm involves the following steps (for mathematical details, see the Appendix, or Wolf et al., 2015): 1. Set initial activation and valence values for all the nodes. 2. For every node, update valence and activation nodes by summing up the (excitatory and inhibitory) input from all the connected nodes. At this step, valence and activation values are multiplied as a way to model emotional biases in cognition (Thagard, 2006). 3. Repeat step 2, until the whole network settles into a stable state; i.e., no significant further changes occur as a result of updating valences and activations. Typically (although not necessarily), this stabilization occurs after a few hundred iterations. The final, stable pattern of valences and activations can be interpreted as a coherent set of attitudes and behaviour tendencies of an agent.

Empirical grounding. Unlike many other agent-based models, which are more abstract and theoretical in nature, InnoMind was designed as a complementary tool to morecustomary research methods in psychology such as (qualitative and quantitative) surveys and experiments. Empirical data can serve as input to InnoMind simulations; on the other hand, simulation outputs can (and should) be tested against empirical data to ensure the validity (or at least: plausibility) of the model.

Table 9. Transportation needs in the InnoMind agent-based model

1. Safety
2. Comfort
3. Environmental Friendliness
4. Driving Experience
5. Image/Self Presentation
6. Costs (Efficiency of)
7. Stress (Avoidance of)
8. Independence

Generating empirical input to the model requires determining the needs and actions relevant to a particular problem domain as well as specifying the following input parameters: 1. importance of the needs to representative subjects from the population one attempts to model; 2. emotional valences of the needs; 3. strength of the excitatory and inhibitory links between specific needs and specific actions. In the development of InnoMind, these parameters were based on data from an extensive empirical study with traditional psychological research methods briefly summarized as follows (see Wolf et al., 2015, for more details). Focusing on the city of Berlin, Germany, the study was about assessing people's attitudes towards different means of transportation. In a first step, multiple focus groups served to qualitatively explore the needs and emotions relevant to people's transportation decisions in general. The resulting set of transportation needs that is implemented in the current InnoMind model is displayed in Table 1. In a second step, a questionnaire was designed to elicit from a stratified sample of residents of Berlin quantitative ratings of the relative importance of the transportation needs, the emotional valence attached to them, as well as the perceived degree to which these needs can be satisfied by using different means of transportation such as cars (traditional or electric), bicycles, trains and buses, and car-sharing. These different means of transportation are implemented in InnoMind as action nodes (see Fig. 1(A)). The empirical data from the survey was used to parameterize the individual agents of the InnoMind model (N = 675). Each survey respondent is represented in the model by one uniquely parameterized neural network model. The parameters such as link strength, valence of nodes, and socio-demographic characteristics are based on the answers in the survey, as shown in Table 2 (see the Appendix or Wolf et al., 2015, for more details).

The survey also contained questions about the actual current use of the different means of transportation. To test the validity of the individual-level agent models of InnoMind, we regressed these self reports on the activation output parameters of the corresponding action nodes after running the parallel-constraint-satisfaction algorithm on each of the artificial agents as described in the previous section. R_2 coefficients thus obtained indicated the individual-level InnoMind model to predict variance shares between 26.1% (for public transport) and 46.2% (for bicycles) of actual (self-reported) transportation-related behaviours (Wolf et al., 2015). Please note that this validation procedure does not involve fitting the model directly to the target behaviour, as is often done in social simulation. Rather, only empirical measures of beliefs and emotions were taken to initialize the model, and then simulation outputs were taken to predict the independently obtained self-reports of behaviors. The InnoMind model thus compares well against the established standards in social psychological attitude-behaviour research, typically employing regression or structural equation models, which yield similar levels of prediction (Armitage & Conner, 2001).

Table 10. Sample survey questions for parametrization of InnoMind agents

Mental representation	HOTCO network element	Example of survey item	Measurement
Cognitive belief	Connection weight between need and action node	e.g. “Driving a car facilitates my need of comfort.”	6-point Likert scale
Emotion	Valence weight attached to action node	e.g. “How good vs. bad does driving a car feel?”	9-point semantic differential scale
Priority	Priority weight of needs	e.g. “How important is the need comfort for you?”	6-point Likert scale

The Interaction Level: Modeling Inter-Agent Persuasion

At the level of interactions, InnoMind models attitude changes, which result from communicating with other agents, as a change in the strengths of the links between nodes of the neural networks that represent the agents’ beliefs and emotions (cf. Monroe & Read, 2008). InnoMind can model interpersonal communication between individual agents as well as mass media communication of one agent to many agents at the same time.

Theoretical background. In line with the abovementioned interacting-dual-systems models of attitudes (e.g., Fazio & Towles-Schwenn, 1999; Gawronski & Bodenhausen, 2007), psychological theories of interpersonal persuasion have proposed a dichotomy of more elaboration-intense and systematic versus more peripheral and heuristic mechanisms of changing people’s minds through communication (e.g., Chen & Chaiken, 1999; Petty & Cacioppo, 1986). Emotions play a role at different levels of elaboration intensity, albeit in different ways: while people consciously reflect on their emotions when engaging in systematic elaboration of other people’s influence attempts, they automatically transfer the valence of their emotions to their attitudes when engaging in only peripheral information processing (Petty & Briñol, 2015). From theories of attitude congruence and biased information processing (e.g., Hegselmann & Krause, 2002; Kunda, 1990; Osgood & Tannenbaum, 1955; Sherif & Hovland, 1961; Westen, Blagov, Harenski, Kilts, & Hamann, 2006) it is well known that the likelihood of one person influencing another person’s attitudes through communication, whether through systematic or heuristic mechanisms, depends on the initial similarity of their attitudes. If two people are too far apart in their opinions, influence attempts will often be unsuccessful or might even backfire.

Computational implementation. Following Thagard and Kroon’s (2006) simulation model of decision-making in small groups, InnoMind implements elaboration-intensive versus peripheral persuasion as two computational mechanisms, displayed in Fig. 1(B). Means-ends communication changes the strength of the links between need and action nodes, modeling the change of cognitive beliefs about the degree to which a specific action is conducive to a specific need. Emotional contagion changes the strength of the links between action and valence nodes, modeling the transfer of emotional valence to an attitude object (cf. Petty & Briñol, 2015). The numerical degree of these changes in a simulated influence attempt between two agents depends on the prior attitude congruence between the two agents. Mathematical details are available in the Appendix.

Empirical grounding. The exact parameters of the link-strength changes as agents communicate with each other are based on empirical data from a psychological experiment designed specifically for maximizing the empirical plausibility of the communication mechanisms embedded in InnoMind. A full description of this experiment is in preparation at the time of this writing; a summary is provided by Wolf et al. (2015). Participants in the experiment responded to vignettes simulating persuasion attempts to evoke positive or negative change in attitudes about the use of conventional and electric cars. For the vignettes, means-ends versus emotional communication and different degrees of prior attitude congruence were systematically varied, and resulting belief and emotional changes in attitudes elicited from the participants.3 The data were used to optimize a function that quantifies the degree of changes in cognitive beliefs and emotional valence during a persuasion attempt, which in turn is implemented as a model of inter-agent attitude change in InnoMind (for details, see Table D.1 in the Appendix or Wolf et al., 2015).

The Society Level: Modeling Communication Flows in Social Networks

Besides modeling how agents can influence each other, an agent-based model needs to specify which agents can be expected plausibly to interact with each other. To this end, InnoMind generates an artificial social network that defines the possible exchange of information among agents in the simulated social system.

Theoretical background. Sociologists have shown that the structure of realistic social networks follows a principle of homophily, according to which individuals tend to prefer interactions with other individuals who are similar to themselves over interactions with individuals who are different in terms of socio-demographic characteristics and values (McPherson et al., 2001). Societies can thus be described as networks of clustered, relatively homogeneous sub-networks of people who have stable local belief systems that are resistant to change as people create “shared realities” (Hardin & Higgins, 1996) with like-minded people (Homer-Dixon et al., 2013). There are also geographical facets of homophily, created both by a tendency of people to move to locations more compatible with their ways of thinking and by the processes of social influence and persuasion exerted over people by their immediate physical neighbours (e.g., Latané & Bourgeois, 2001; Otte & Baur, 2008; Rentfrow, Jost, Gosling, & Potter, 2009; Onnela et al., 2011).

Computational implementation. As displayed in Fig. 2, InnoMind models flows of communication within an artificial social network that is geographically explicit and implements the principle of homophily. Setting up this network requires two sets of parameters. The first is a social radius (cf. Hamill & Gilbert, 2009; see the dashed circle in Fig. 2) given by (1) the geographic proximity of agents to allow for the fact that interactions are more likely between people who live close to each other, whether or not they have similar demographic characteristics and lifestyles, and (2) the size of agents' egocentric social networks (represented by circles such as in Fig. 2 of different sizes) to allow for the fact that some people are subject to more social influence than others (e.g., extraverted people might have more friends than introverted people). The second parameter needed for generating an artificial social network in InnoMind is a mathematical operationalization of social similarity, based on the concept of Blau space (McPherson, 1983). Blau space is a multi-dimensional space whose base dimensions are given by socio-demographic variables. InnoMind uses six variables (gender, income, age, education level, and indices of modernity and consumption preferences) to compute for any other agent within one agent's social radius a Euclidean distance measure of social dissimilarity in Blau space. When setting up the ties in the artificial social network, InnoMind uses a weighted random procedure based on that Blau space distance (see Appendix B). As a result, the likelihood of sociodemographically similar and geographically close people to interact with each other is higher, albeit it is not fully impossible for two socially and geographically distant agents to engage in an interaction – just as in real societies where communication generally follows the homophily principle while sometimes interactions still do occur between people of different social backgrounds.

Empirical grounding. The survey of Berlin residents described above, which was used to parameterize the individual-level models of attitudes in InnoMind, also contained the necessary data for empirically grounding the social network model. As was mentioned above, one InnoMind agent corresponds to one unique survey respondent. Postal codes obtained from the respondents served as a rough estimate of geographical location. The social radius (dashed circle in Fig 2.) was assessed through specifically designed questions about selfreported opinion leadership and social orientation of survey respondents in the process of innovation adoption. The variables defining social closeness in Blau space were taken from respondents' socio-demographic characteristics and their answers on an established German questionnaire measuring lifestyles and consumption preferences (Otte, 2005; Otte & Baur, 2008).

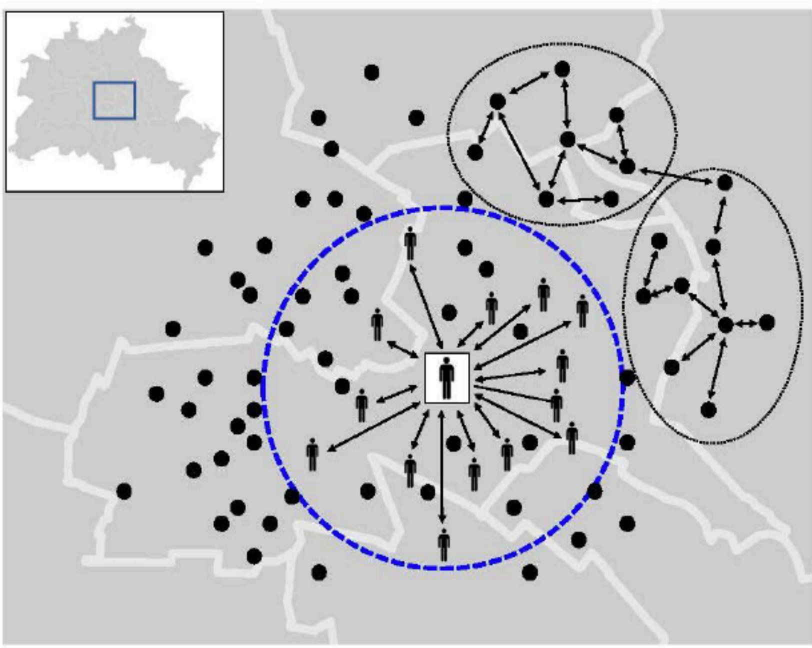

Figure 12. Geographically explicit social network model in InnoMind
Here, the Friedrichshain-Kreuzberg district of Berlin is displayed in the centre of the map. Location of agents is based on postal codes obtained from a stratified survey of Berlin residents.

Case Study: Promoting Carsharing in Berlin

In this section, we will show how we can use the InnoMind agent-based model to support the spread of pro-environmental attitudes and behaviours. As a case study, we will consider the promotion of carsharing in the city of Berlin, Germany. Carsharing is widely believed to be a more sustainable form of urban transportation than individual car ownership, particularly if electric or hybrid vehicles are used (Frinkorn & Müller, 2011; 2015). For example, carsharing reduces the amount of kilometers traveled and, hence, carbon and other emissions, lends itself better to a multi-modal combination with public transportation, and allows more efficient land-use. Persuading more and more urban residents to participate in carsharing would thus likely lead to more environment-friendly cities - a typical goal an environmental psychologist might want to support. An important research question related to this goal could be: How should a campaign be designed that aims at influencing residents' attitudes and behaviors in support of carsharing?

Using InnoMind to Simulate Campaigns That Promote Car Sharing

It is well known in psychology that the same facts or actions can be framed semantically in different ways and that the framing chosen can have tremendous impact on the persuasiveness of a message related to these facts or actions (e.g., Gifford & Comeau, 2011; Lakoff, 2004; Levin, Schneider, & Gaeth, 1998). The success of a campaign targeted at improving the environmental friendliness of people's behaviours will, hence, depend considerably on the framing chosen. For example, one might directly emphasize the fact that carsharing is beneficial for the environment, one might make its cost-efficiency salient, or one might choose to portray carsharing as "cool" and innovative. Which one of these, or other, campaign framings will work best depends on the emotional coherence of these arguments with people's preexisting beliefs and attitudes (Thagard, 2006; Westen, 2007). Various empirical evaluation studies lend support to the idea that people's transportation choices can indeed be influenced by persuasive campaigns tailored to people's needs and attitudes (e.g., Anable, 2013; Brög, Erl, Ker, Ryle, & Wall, 2009; Cairns, Sloman, Newson, Anable, Kirkbridge, & Goodwin, 2008). The InnoMind model not only provides a mechanistic explanation for such findings, but can be used for ex-ante evaluation of different campaign strategies through simulated scenarios.

Social simulation vs. experimental psychology. The standard methodological procedure for an environmental psychologist to answer questions about suitable framings would be to design an experiment to determine the effectiveness of different campaign strategies empirically. However, experiments are costly to be carried out, they usually only allow for 2-3 variables to be studied at a time, and they neglect the complexity of communicative dynamics in a real social system where there is not just one controlled message going from advertisers to consumers, but also self-organized communication among consumers that interacts with the actions of campaigners. Agent-based models like InnoMind, in contrast, are economical tools for testing the plausible effectiveness of different possible campaign frames in simulations, which amount to virtual experiments (e.g., Delre et al., 2007; Mosler & Martens, 2008; Tobias, 2009). This statement is not meant to dismiss the importance of empirical and experimental work; as explained in the previous section, the model is carefully grounded in customary empirical research, which now can be capitalized upon in order to come up with quick, psychologically sound answers to many practical questions related to sustainable transportation.

Computational implementation of campaign framing. In InnoMind, a mass media campaign can be simulated through a special kind of agent called a media agent. Media agents differ from the other agents in that their communication is uni-directional; i.e., they can send messages directly to a large number of individual agents, but they will not receive communication back from them. Also, media agents are connected to larger numbers of agents in the virtual society than ordinary agents, in order to simulate communication through mass media. Other than that, communication through the media is modeled in the same way as interpersonal persuasion, described in the preceding section of this paper. Hence, a simulated media campaign relies on the two possible communication mechanisms, targeted at changing beliefs about need-action contingencies versus emotional connotations attached to these beliefs (see above).

We used the empirically derived model of eight different needs that influence people's transportation attitudes and behaviours (see Table 1) for guiding ideas about possibly successful campaign strategies. Therefore, our approach falls under the category of goal framing, where persuasion attempts emphasize specific psychological goals that can be achieved through the actions in question (Levin et al., 1998; Lindenberg & Steg, 2007). The two questions we sought to answer with the present simulation experiment is: (1) Which transportation needs should be emphasized in a pro-carsharing campaign in Berlin, if the goal is to maximize the number of Berlin residents willing to adopt this innovative and environmentally friendly means of transportation? (2) Should different needs be emphasized to target different segments of the Berlin population?

Table 2 displays the computational implementation of the various possible goal framings of our simulated carsharing campaign. In a mass-media persuasion attempt, all agents connected to the media agent (70% of the agent population) would change the link between the node representing the need emphasized by the campaign and the carsharing action node by the amount displayed in the table (without, however, exceeding the maximal link weight of +1). Note that we leave the connections with all other action nodes representing means of transportation besides carsharing unchanged. For example, a campaign focused on environmental friendliness ("Go green: Use carsharing!") would result (only) in a modified link between the environmental-friendliness node and the carsharing node. In contrast, a campaign emphasizing independence and flexibility ("Never look for a parking spot again: Use carsharing!") would be simulated by the agents connected to the media agent changing (only) the link in their neural networks between the independence and the carsharing node. Please note carefully that the numbers displayed in Table 2 only represent the information sent by the media agent, which does not necessarily result in a change of the same amount or even direction in the receiving agents' attitude networks due to the nonlinear nature of the parallel constraint satisfaction network algorithm. As was explained in the previous section, the actual change in the receivers' representation is a function of prior belief congruence between sender and receiver, as the InnoMind agents engage in motivated cognition similar to humans. Therefore, the outcome of this campaign-frame experiment is much less trivial than the numbers in Table 2 might suggest and we need to run computer simulations to handle the resulting complexity. In addition, the change of minds is not over after a single-shot message sent over the media, but such a communication impulse can be expected to stimulate further interpersonal communication in the social networks of the agents, which needs to be taken into account.

Table 11. Simulated carsharing campaigns and their computational implementation

Need node	Campaign frame	Change of weight between carsharing node and respective need node
N1 (safety)	Carsharing is safe	+1
N2 (comfort)	Carsharing is comfortable	+1
N3 (eco-friendliness)	Carsharing is green	+1
N4 (driving experience)	Carsharing makes for a great driving experience	+1
N5 (image)	Carsharing is cool	+1
N6 (cost avoidance)	Carsharing is cheap	+1
N7 (no stress)	Carsharing is free from stress and hassles	+1
N8 (independence)	Carsharing allows maximal flexibility	+1

Running simulations with InnoMind. The steps involved in running a simulation with InnoMind are displayed in Fig. 3. Every simulation starts with an initialization of all the agents' mental representations and their socio-economic attributes, which are used to set up the social network connections between agents, as explained in the previous section. For the simulation of different carsharing campaigns, we based the initialization on the results of the survey related to transportation attitudes and behaviour in Berlin described above. We then advance the simulation one time step ("t=t+1" in Fig. 3).

The first set of computations occurs at the level of individual agents: Using the connectionist algorithm described in the previous section, the model determines for each agent a preferred mode of transportation out of five options (i.e. conventional and electric car, public transport, carsharing and bicycle), which corresponds to the action node with the highest activation parameter once the neural network has settled after exchanging activation iteratively among all nodes. Next, each agent picks one other agent from its individual social network (see Fig. 2) at random, and the two exchange information via the two communication mechanisms of the model (means-ends and emotional contagion). This exchange of information results in an adjustment of the connection weights in the two neural networks representing the communicating agents; however, the degree of this adjustment is contingent on prior belief congruence (see above). Up to this step, we have only simulated interpersonal communication in the social system, without external intervention through a media campaign. If no such intervention is implemented, the simulation is advanced one further time step and the cycle of updating individual beliefs and exchanging information among agents reiterates. We conducted such a simulation of 100 time steps to generate a baseline scenario for the change of attitudes toward carsharing in Berlin without any media campaign. In the logic of experimental psychology, this baseline scenario corresponds to the control condition.

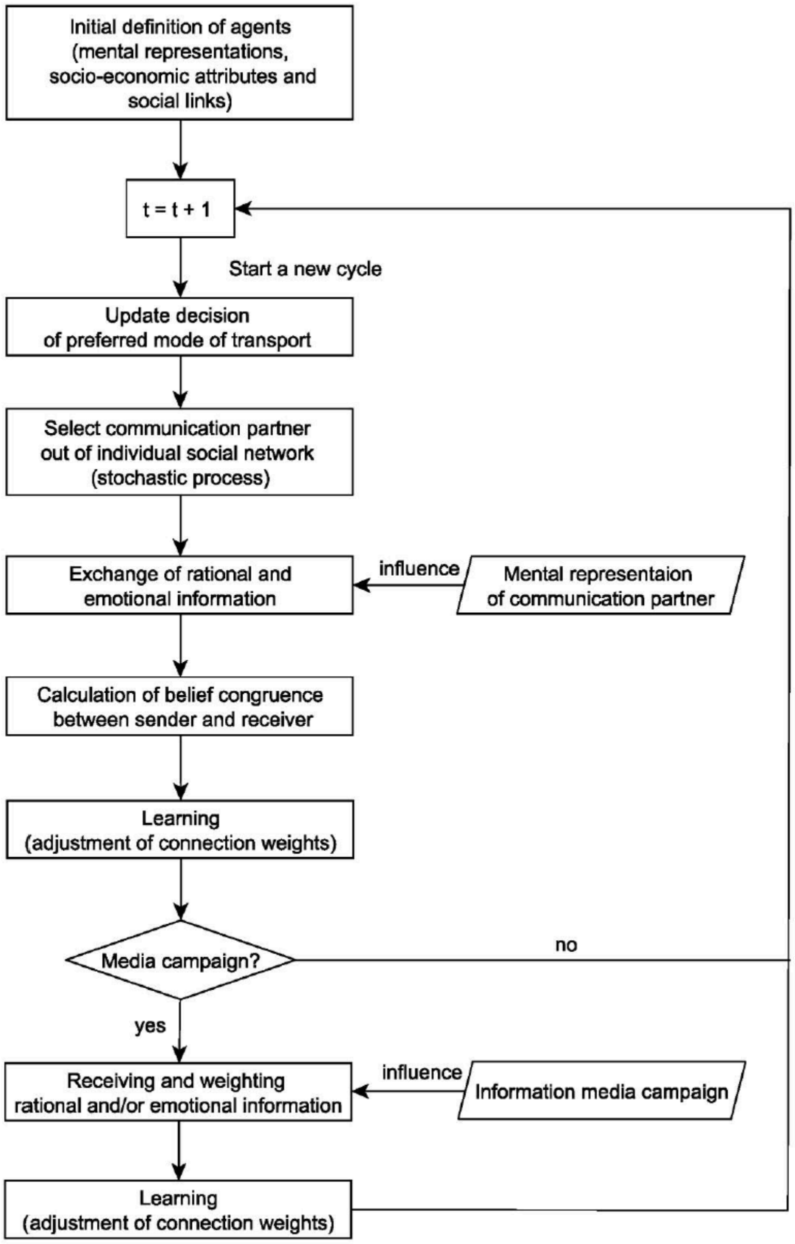

Figure 13. Flowchart of simulations with InnoMind

If, however, a media campaign is implemented in an iteration, two additional steps are required after the agent neural networks adjusted their connection weights following agent-to-agent communication.

First, a certain proportion of all agents chosen at random receive communication from the special media agent, simulating the broad distribution of a message in society through mass media communication. The mechanisms for communication between the media agent and the ordinary agents are exactly the same as for agent-to-agent communication, i.e., the media agent also communicates facts or emotions. The only difference is that the media agent is far more connected than all the ordinary agents: In the present simulations, 70% of agents chosen at random received the media agent's messages.

Second, upon receiving a media message, all agents adjust their neural network connection weights according to the usual function, depending on prior belief congruence with the media agent. Then, the simulation advances one time step and the cycle depicted in Fig. 3 repeats. In the simulations of carsharing campaigns reported here, we implemented a media message in every 10th iteration.

Results

The results presented in this section are focused on changes in attitudes towards carsharing, resulting in changing preferences for carsharing as compared with other means of transportation. Technically, we assume that an agent's preferred mode of transportation is carsharing if after running the connectionist decision algorithm at the individual level the activation value of the carsharing action node outweighs activation values of all the other nodes (for additional details, see Wolf et al., 2015). Graphs and figures present the fraction of agents (averaged across 5 runs of the InnoMind simulation) that prefer carsharing. All simulation experiments are conducted separately with specific interventions under identical starting conditions in the agent population. Attitude changes caused by social and media influence are compared against a baseline scenario (i.e., control condition) in their overall and geographically nuanced effectiveness.

Expected attitude change with and without intervention. Fig. 4 compares the temporal dynamics of carsharing preferences after agents' exposure to 8 different simulated campaigns, plus a baseline scenario (control condition) where no media campaign is implemented. The moderate increase from roughly 4% (t=1) to about 8% (t=100) in the baseline scenario reveals a stable trend of increasingly more positive attitudes towards carsharing on a relative low level, resulting from utual social influence among agents. In contrast, the simulated attitude changes resulting from mass media influence suggest that specifically framed campaigns, addressing different needs of consumers, can induce substantial attitudinal changes toward carsharing, resulting in a proportion of up to 35% of the population who would consider carsharing as their preferred mode of transport. Interestingly, campaigns framing independence, safety and the avoidance of stress when using carsharing; not, as one might expect its environmental friendliness, are the three most effective strategies to support this transport mode, according to our simulations.

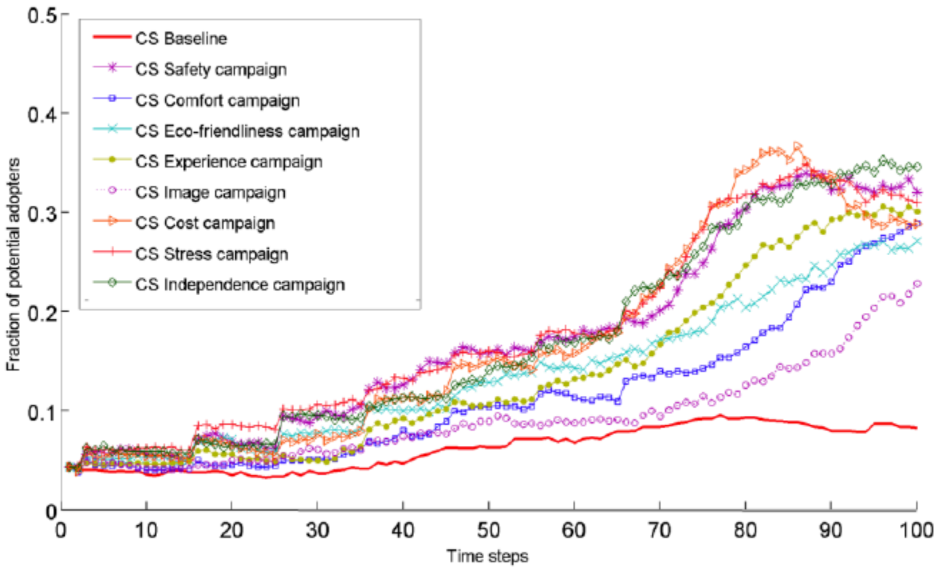

Figure 14. Simulation results (main effects)

Effectiveness of different carsharing campaign frames predicted by InnoMind simulations, compared with a baseline scenario, in which no campaign is implemented.

The effectiveness of campaigns promoting the use of more sustainable means of transportation such as carsharing depends on a general pattern of transport mode shift, in particular the reduction of the use of privately owned internal-combustion-engine cars. It would be problematic in terms of sustainability goals if the increase in carsharing were to happen at the expense of even more sustainable transportation options such as public transport or bike riding. Therefore, we also analyzed the comparative effect of such carsharing campaigns on the attitudes towards other transportation options, as suggested by our simulations.

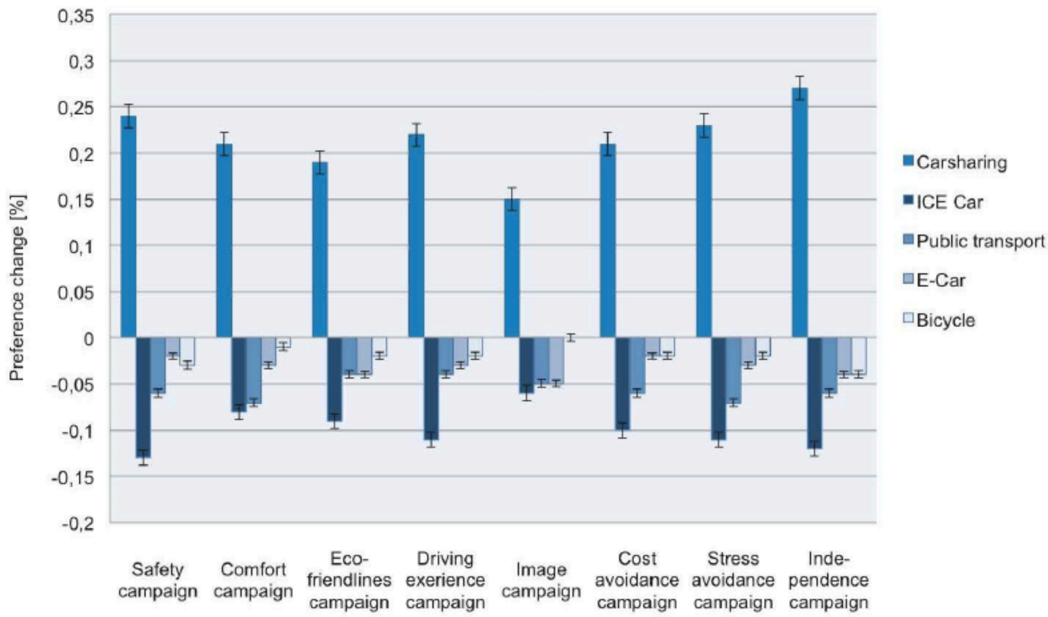

Figure 15. Comparative change in transportation preferences after different carsharing campaigns suggested by simulations with InnoMind.

The figure displays the average change in activation of the action nodes corresponding to means of transportation across all agents after 100 time steps.

Fig 5. shows the in-/decrease of preferences for five transportation modes resulting from the simulated media campaigns for carsharing relative to the baseline after 100 time steps of the simulation. The results indicate that the substantial increase of the fraction of agents changing their preferences towards carsharing (between 15% and 27%) is across all campaigns - as intended - mostly at the expense of combustion-engine car ownership.

However, media campaigns addressing needs such as independence, safety or the avoidance of stress may also result also in an unforeseen mode shift by reducing the preferences for public transport and bicycle (together between -9% and -10%). Thus, besides the varying effectiveness of campaigns caused by the different susceptibility of individual agents in the context of their specific preexisting mental representations, our results indicate that campaign strategies must also target groups of travellers with preferences for high carbon emission vehicles to facilitate a more sustainable transportation system (see also Wolf et al., 2015).

Geographic location as a moderator of campaign effectiveness. In addition, we analyzed the effectiveness of the different campaigns in the spatial domain - an equally important aspect for the implementation of media campaigns. Owing to the non-random distribution of people with specific attitudinal patterns across geographic locations, we can expect different campaign frames to be of different effectiveness in different locations - in statistical terminology, we would call this an interaction effect.

The geographically nuanced fraction of agents predicted to prefer carsharing after implementing the different campaigns (including baseline scenario) in InnoMind is shown in Fig. 6. Note that the geographical location of the agents in InnoMind is based on the postal codes of their corresponding survey respondents as a proxy for residential location. Each map indicates the predicted attitude changes separately for the 12 administrative districts of the city of Berlin. The dark (light) colors represent districts with a high (low) percentage of agents with preferences for carsharing. The maps indicate pronounced differences in the responsiveness to the differently-framed campaigns across the city. The results illustrate that while some campaigns such as the intervention emphasizing independence and flexibility of carsharing lead to broad positive attitude changes across the city, other campaigns communicating aspects such as environmental friendliness or positive driving experience induce specific regional effects.

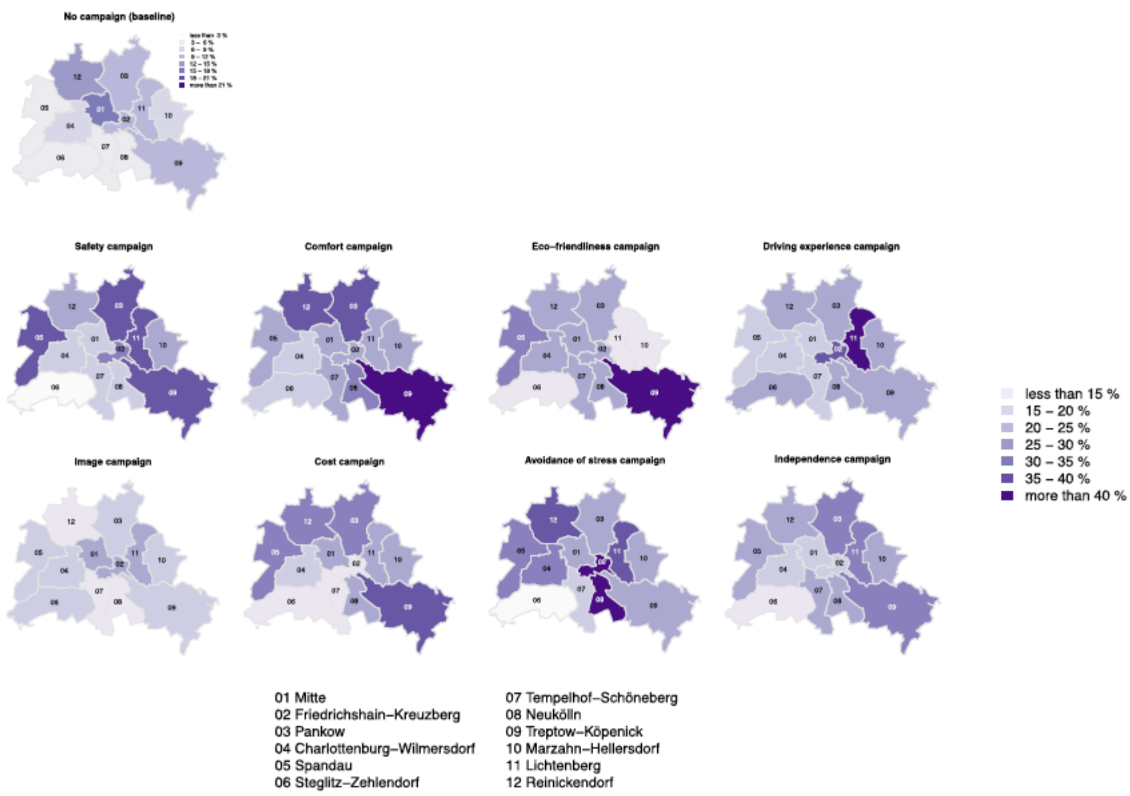

Figure 16. Simulation results (interaction effects)

The effectiveness of different carsharing campaign frames depends on geographic location (i.e., district of Berlin).

Discussion

As an example for the usefulness of agent-based modeling (ABM) in environmental psychology, we discussed in this paper our recently developed InnoMind model, aimed at explaining the change of attitudes towards social and technological innovations in a social system (Wolf et al., 2015). We explained here how this ABM allows researchers interested in large-scale changes of environmental attitudes and behaviours to study the interplay of relevant mechanisms at the individual, interpersonal, and societal levels of explanation. As we showed, InnoMind is not only based on up-do-date theories from social psychology, cognitive science, and sociology, but also carefully grounded in empirical data obtained with traditional research methods from psychology and social science such as experiments and both qualitative and quantitative surveys.

Agent-based models of innovation diffusion are abundant, including the domain of sustainable transportation (e.g., Brown, 2013; Eppstein, Grover, Marshall, & Rizzo, 2011; Janssen & Jager, 2002; Kiesling, Günther, Stummer, & Walkobinger, 2011). Our model adds to this literature, although attitude dynamics on the consumer side are only one aspect of innovation diffusion, while the inclusion of technological, supply-side, and legal developments remains an open question for future research. We think that the value added from our model to the work on innovation diffusion in social simulation comes through the theoretical grounding in cognitive science (cf. Sun, 2012); in particular up-to-date theorizing on the role of emotion in human decision-making (Simon et al., in press; Thagard, 2006). Despite some notable exceptions (e.g., Schwarz & Ernst, 2009), innovation-diffusion models have been criticized for oversimplifying the psychological decision-making processes of agents (Kiesling et al., 2011, Squazzoni et al., 2014; Sun, 2012). With our InnoMind model, we answer the calls for more psychological realism in social simulations by bridging the gap to connectionist models of social psychological processes (e.g., Monroe & Read, 2008; Orr et al., 2013; Schröder & Thagard, 2014; Van Overwalle & Siebler, 2005). These latter approaches provide good explanations of attitude-behaviour relationships, but tend to remain restricted to the individualistic perspective of psychology, which we sought to overcome with the development of InnoMind.

The second contribution of this paper besides demonstrating the usefulness of social simulation in environmental psychology is pragmatic. We used the InnoMind model to evaluate the plausible effectiveness of different campaign strategies targeted at raising the public's acceptance of carsharing, a combined technological and social innovation that many regard as a more sustainable form of urban transportation than car ownership. While the simulation results provide clear guidance for designing such campaigns, a few words of caution related to some limitations of the model are in order.

First, the fraction of future carsharing users suggested in the different simulated scenarios should not be seen as precise predictions because the presented simulations disregard many other communicative processes such as advertising by carmakers or political debates in the media about sustainable transportation and urban futures. Like any experiment in psychology, the results of the simulations can be considered valid all else being equal; hence, the interpretation should only be about the psychologically plausible effectiveness of campaigns compared with each other, not about the absolute effectiveness of any such campaign.

Second, the distribution of agents in the districts of Berlin (Fig. 6) does not fully correspond with the real world, as the survey sample underlying this artificial society is quasi-representative for the population of Berlin as a whole, but not necessarily the single districts of the city. A more fine-grained resolution of the underlying survey data would be required to gain more confidence in the location-specific predictions. Despite this limitation, the identified spatial patterns are in line with the above-mentioned aspects of geographical homophily and may serve as hypotheses that can be tested empirically in future studies. It is important that such work be carried out in the future to gain more confidence in the reliability and validity of InnoMind.

We made clear that we do not view ABM as a surrogate to the predominant experimental research methods in psychology, but rather as a complementary method that helps to overcome the individualistic biases inherent in those experimental approaches. The logic of our simulation approach is very similar to the logic of experimental psychology. We used the InnoMind model to compare different ways of framing a campaign against a baseline, or control condition, all other variables held constant. Hence, we might call our method a virtual experiment. While one might be inclined to trust data from real experiments more than data generated by a computer model, the trustworthiness of experimental findings has been the subject of much debate recently as well (e.g., Open Science Collaboration, 2015; Stroebe & Strack, 2014), so we believe there are no simple answers here. The clever combination of experimental/empirical and computational/theoretical methods provides the best path to understanding in our opinion.

A further advantage of simulation experiments over real experiments is the relative cost-effectiveness of the former. It took us only a few hours to come up with the results presented here and cost virtually no money. In comparison, a real experiment with participants recruited in all the different districts of Berlin would have taken months and incurred considerable monetary costs. It should, of course, be noted that this claim is only true because of our previous considerable investment in the development of InnoMind in the first place (Wolf et al., 2015). Only now that the model already exists and has been shown to generate plausible and valid results can we use it to come up with quick answers about people's attitudes towards different means of more or less sustainable forms of transportation. Extensions of the realm of the model beyond transportation will not be doable within hours, to be sure, but InnoMind with its generic attitude structure as a network of needs, actions, and emotional valences (see Fig. 1) lends itself to relatively simple adaptation to other problem domains. One could use the empirical studies related to transportation used as a basis for the development of InnoMind (see Wolf et al., 2015) as a blueprint for future studies intended as starting points for simulations in other domains of environmental behaviour. In addition, it is entirely possible to take quick expert judgments as viable starting points for simulations. Hence, the model is flexible enough to be tailored to different research questions with different amounts of available resources, with results ranging from quick educated guesses to fully fledged-out data-driven strategy development. It is this flexibility, besides their accounting for social dynamics, that makes social simulations tools important methodological complements to traditional research methods in environmental psychology.

Notes

1. The source code of the model, which is written in Java, is available online at the openABM agent-based modeling platform. (EXACT URL will be provided during the production stage of the paper)

2. Please note that the definition of „needs“ is pragmatic here, referring to people’s selfreported desirable qualities of transportation rather than to universal functional requirements of organisms as in scientific theories of needs. In German language, the term Mobilit.tsbedürfnisse (=transportation needs) is often used in transportation research (e.g., Hunecke, 2015).

3. Here are two examples of vignettes implementing the two different communication mechanisms. Means-end/communication of facts: „I encourage you to give up driving internal combustion engine cars. On the one hand, cars cause considerable environmental damage and are a threat to our future. On the other hand, speed limits and the increased lack of parking space considerably restrict independence and individual freedom when using the car.“ Contagion/communication of emotions: „Driving cars is really fun! Last weekend I drove the car at its limits in the countryside during gorgeous weather. That is what I call fun! I really don´t know what all the people talk about if they say we should drive more fuelefficient or even give up driving in general. That is just nonsense!“

References

Ajzen, I. (1989). Attitude structure and behavior. In A. R. Pratkanis, S. J. Breckler, & A. G. Greenwald (Eds.), Attitude structure and function (pp. 241-274). Hillsdale, NJ: Lawrence Erlbaum.

Anable, J., (2013). SEGMENT WP3 - Final report. Retrieved September 21st, 2015 from http://www.segmentproject.eu/hounslow/segment.nsf/Files/SFF-267/$file/Del%203.6%20WP3%20FINAL%20REPORT.pdf

Armitage, C. J., & Conner, M. (2001). Efficacy of the Theory of Planned Behaviour: A metanalytic review. British Journal of Social Psychology, 40, 471-499.

Bargh, J. A., & Chartrand, T. L. (1999). The unbearable automaticity of being. American Psychologist, 54, 462-479.

Brög, W., Erl, E., Ker, I., Ryle, J., Wall, R. (2009). Evaluation of voluntary travel behavior change: experiences from three continents. Transport Policy, 16, 281-292.

Brown, M. (2013). Catching the PHEVer: Simulating electric vehicle diffusion with an agentbased mixed logit model of vehicle choice. Journal of Artificial Societies and Social Simulation, 16(2): 5.

Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A., Goodwin, P., (2008). Smarter Choices: assessing the potential to achieve traffic reduction using ‘soft measures’. Transport Reviews, 28, 593–618.

Chen, S., & Chaiken, S. (1999). The heuristic-systematic model in its broader context. In S. Chaiken & Y. Trope (Eds.), Dual process theories in social psychology (pp. 73-96). New York: Guilford.

Cunningham, W. A. & Zelazo, P. D. (2007). Attitudes and evaluations: A social cognitive neuroscience perspective. Trends in Cognitive Sciences, 11, 97-104.

Delre, S. A., Jager, W., Bijmolt, T. H. A., & Janssen, M. A. (2007). Targeting and timing promotional activities: An agent-based model for the takeoff of new products. Journal of Business Research, 60(8), 826–835.

Duncan, S., & Barrett, L. F. (2007). Affect is a form of cognition: A neurobiological analysis. Cognition & Emotion, 21, 1184-1211.

Ehret, P. J., Monroe, B. M., & Read, S. J. (2015). Modeling the Dynamics of Evaluation: A Multilevel Neural Network Implementation of the Iterative Reprocessing Model. Personality and Social Psychology Review, 19, 148-176.

Epstein, J. M. & Axtell, R. L. (1996). Growing artificial societies: Social science from the bottom up. Cambridge, MA: MIT Press.

Eppstein, M. M. J., Grover, D. K., Marshall, J. S., & Rizzo, D. M. (2011). An agent-based model to study market penetration of plug-in hybrid electric vehicles. Energy Policy, 39, 3789-3802.

Fazio, R. H. & Towles-Schwenn, T. (1999). The MODE model of attitude-behavior processes. In S. Chaiken & Y. Trope (Eds.), Dual Process Theories in Social Psychology (pp. 97-116). New York: Guilford.

Firnkorn, J., & Müller, M. (2011). What will be the environmental effects of new freefloating carsharing systems? The case of car2go in Ulm. Ecological Economics, 70(8), 1519–1528.

Firnkorn, J., & Müller, M. (2015). Free-floating electric carsharing-fleets in smart cities: The dawning of a post-private car era in urban environments? Environmental Science & Policy, 45, 30–40.

Fishbein, M., & Ajzen, I. (2010). Predicting and changing behavior: The reasoned action approach. New York: Psychology Press (Taylor & Francis). Friedkin, N. E., & Johnsen, E. C. (1999). Social influence networks and opinion change.

Advances in Group Processes, 16, 1-29. Gawronski, B. & Bodenhausen, G. V. (2007). Unraveling the processes underlying evaluation: Attitudes from the perspective of the APE model. Social Cognition, 25, 687-717.

Gifford, R., & Comeau, L. A. (2011). Message framing influences perceived climate change competence, engagement, and behavioral intentions. Global Environmental Change, 21, 1301-1307.

Glöckner, A., & Betsch, T. (2008). Modeling option and strategy choices with connectionist networks: Towards an integrative model of automatic and deliberate decision making. MPI Collective Goods Preprint, 2008/2.

Glöckner, A., Hilbig, B. E., & Jekel, M. (2014). What is adaptive about adaptive decision making? A parallel constraint satisfaction account. Cognition, 133(3), 641–666.

Hamill, L., & Gilbert, N. (2009). Social circles: A simple structure for agent-based social network models. Journal of Artificial Societies and Social Simulation, 12(2).

Hardin, C. D., & Higgins, E. T. (1996). Shared reality: How social verification makes the subjective objective. In E. T. Higgins & R. M. Sorrentino (Eds.), Handbook of motivation & cognition: The interpersonal context (vol. 3, pp. 28-84). New York: Guilford.

Hegselmann, R., & Krause, U. (2002). Opinion dynamics and bounded confidence models: Analysis and simulation. Journal of Artificial Societies and Social Simulation, 5(3).

Helbing, D., & Balietti, S. (2012). Agent-based modeling. In D. Helbing (Ed.), Social selforganization (pp. 25-70). New York, NY: Springer.

Homer-Dixon, T., Leader Maynard, J., Mildenberger, M., Milkoreit, M., Mock, S. J., Quilley, S., Schröder, T., & Thagard, P. (2013). A complex systems approach to the study of ideology: Cognitive-affective structures and the dynamics of belief change. Journal of Social and Political Psychology, 1, 337-363.

Hunecke, M. (2015). Mobilitätsverhalten verstehen und verändern. Wiesbaden: Springer VS. [Understanding and changing transportation behaviour]

Janssen, M. A., & Jager, W. (2002). Stimulating diffusion of green products. Journal of Environmental Psychology, 12, 283 - 306.

Kiesling, E., Günther, M., Stummer, C., & Walkobinger, L. M. (2011). Agent-based simulation of innovation diffusion: A review. Central European Journal of Operations Research, 20, 183-230.

Kunda, Z. (1990). The case for motivated reasoning. Psychological Bulletin, 108, 480-498.

Lakoff, G. (2004). Don't think of an elephant! Know your values and frame the debate. White River Junction, VT: Chelsea Green Publishing.

Latané, B., & Bourgeois, M. J. (2001). Dynamic social impact and the consolidation, clustering, correlation, and continuing diversity of culture. In M. A. Hogg & S. Tindale (Eds.), Blackwell handbook of social psychology: Group processes (pp. 235-258). Malden, MA: Blackwell.

Levin, I. P., Schneider, S. L., & Gaeth, G. J. (1998). All frames are not created equal: A typology and critical analysis of framing effects. Organizational Behavior and Human Decision Processes, 76, 149-188.

Lindenberg, S., & Steg, L. (2007). Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social issues, 63(1), 117-137.

McClelland, J. L., Mirman, D., Bolger, D. J., & Khaitan, P. (2014). Interactive activation and mutual constraint satisfaction in perception and cognition. Cognitive Science, 38, 1139-1189.

McPherson, M. (1983). An ecology of affiliation. American Sociological Review, 48, 519-532.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. Annual Review of Sociology, 27, 415–444.

Monroe, B. M., & Read, S. J. (2008). A general connectionist model of attitude structure and change: The ACS (Attitudes as Constraint Satisfaction) model. Psychological Review, 115, 733-759.

Mosler, H.-J., & Martens, T. (2008). Designing environmental campaigns by using agentbased simulations: strategies for changing environmental attitudes. Journal of Environmental Management, 88(4), 805–816.

Oishi, S., Kesebir, S, & Snyder, B. H. (2009). Sociology: A lost connection in social psychology. Personality and Social Psychology Review, 13, 334-353.

Onnela, J. P., Arbesman, S., González, M. C., Barabási, A. L., & Christakis, N. A. (2011) Geographic constraints on social network groups. PLoS One 6: e16939.

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. Science, 349(6251), aac4716.

Orr, M. J., Thrush, R., & Plaut, D. C., (2013). The theory of reasoned action as parallel constraint satisfaction: Towards a dynamic computational model of health behavior. PLoS ONE 8(5): e62490.

Osgood, C. E. & Tannenbaum, P. H. (1955). The principle of congruity in the prediction of attitude change. Psychological Review, 62, 42-55.

Otte, G. (2005). Entwicklung und Test einer integrativen Typologie der Lebensführung für die Bundesrepublik Deutschland. Zeitschrift Für Soziologie, 34, 442–467. [Developing and testing an integrated typology of lifestyles for the Federal Republic of Germany]

Otte, G. & Baur, N. (2008). Urbanism as a Way of Life? Räumliche Variationen der Lebensführung in Deutschland. Zeitschrift für Soziologie, 37, 93-116. [Urbanism as a way of life? Geographical variation of lifestyles in Germany]

Pentland, A. (2014). Social physics. New York, NY: Penguin.

Petty, R. E., & Briñol, P. (2015). Emotion and persuasion: Cognitive and meta-cognitive processes impact attitudes. Cognition and Emotion, 29, 1-26.

Petty, R. E., & Cacioppo, J. T. (1986). Communication and persuasion: Central and peripheral routes to attitude change. New York: Springer.

Rentfrow, P. J., Jost, J. T., Gosling, S. D., & Potter, J. (2009). Statewide differences in personality predicting voting patterns in 1996-2004 U.S. presidential elections. In J. T. Jost, A. C. Kay, & H. Thorisdottir (Eds.), Social and psychological bases of ideology and system justification (pp. 314-347). New York: Oxford University Press.

Rogers, E. M. (2003). Diffusion of innovations (5th edition). New York: Free Press.

Scholl, W. (2007). Plädoyer für eine sozialere und dadurch interdisziplinärere und anwendbarere Sozialpsychologie. Zeitschrift für Sozialpsychologie, 38, 273-284. [Pleading for a More Social and thereby More Interdisciplinary and Better Applicable Social Psychology] English translation retrieved December 9th, 2014 from https://www.psychologie.hu-berlin.de/prof/org/download/PladEngScholl07/view

Schröder, T., Stewart, T. C. & Thagard, P. (2014). Intention, emotion, and action: A neural theory based on semantic pointers. Cognitive Science, 38, 851-880.

Schröder, T., & Thagard, P. (2014). Priming: Constraint satisfaction and interactive competition. Social Cognition, 32(Supplement), 152-167.

Schwarz, N., & Ernst, A. (2009). Agent-based modeling of the diffusion of environmental innovations: An empirical approach. Technological Forecasting and Social Change, 76, 497-511.

Sherif, M., & Hovland, C. I. (1961). Social judgment: Assimilation and contrast effects in communication and attitude change. Oxford: Yale University Press.

Simon, D., Stenstrom, D. M., & Read, S. J. (in press). The coherence effect: Blending cold and hot cognitions. Journal of Personality and Social Psychology.

Sobkowicz, P. (2009). Modelling opinion formation with physics tools: Call for closer link with reality. Journal of Artificial Societies and Social Simulation, 12(1).

Squazzoni, F., Jager, W., & Edmonds, B. (2014). Social Simulation in the Social Sciences: A Brief Overview. Social Science Computer Review, 32, 279–294.

Stroebe, W., & Strack, F. (2014). The alleged crisis and the illusion of exact replication. Perspectives on Psychological Science, 9, 59-71.

Sun, R. (2012). Grounding social sciences in cognitive sciences. Cambridge, MA: MIT Press.

Thagard, P. (2000). Coherence in thought and action. Cambridge, MA: MIT Press.

Thagard, P. (2006). Hot thought: Mechanisms and applications of emotional cognition. Cambridge, MA: MIT Press.

Thagard, P., & Aubie, B. (2008). Emotional consciousness: A neural model of how cognitive appraisal and somatic perception interact to produce qualitative experience. Consciousness and Cognition, 17, 811-834.

Thagard, P., & Kroon, F. (2006). Emotional consensus in group decision-making. Mind & Society, 5, 85-104.

Thagard, P., & Verbeurgt, K. (1998). Coherence as constraint satisfaction. Cognitive Science, 22, 1-24.

Tobias, R. (2009). Changing behavior by memory aids: A social psychological model of prospective memory and habit development tested with dynamic field data. Psychological Review, 116, 408–438.

Van Overwalle, F., & Siebler, F. (2005). A connectionist model of attitude formation and change. Personality and Social Psychology Review, 9(3), 231-274.

Westen, D. (2007). The political brain: The role of emotion in deciding the fate of the nation. New York, NY: Public Affairs.

Westen, D., Blagov, P. S., Harenski, K., Kilts, C., & Hamann, S. (2006). Neural bases of motivated reasoning: An fMRI study of emotional constraints on partisan political judgment in the 2004 U.S. presidential election. Journal of Cognitive Neuroscience, 18, 1947-1958.

Wolf, I., Schröder, T., Neumann, J., & de Haan, G. (2015). Changing minds about electric cars: An empirically grounded agent-based modeling approach. Technological Forecasting and Social Change, 94, 269-285.

Appendix

Appendix A. Decision-Making of Individual Agents

The HOTCO model (Thagard, 2006), which we used for modeling individual agents in nnoMind, simulates human decisions as the result of interactive competition of activations and valences of the nodes in an artificial neural network. In an iterative updating algorithm, activations and valences of the units are updated in parallel until they reach a stable level, i.e., the network has settled. Activations are updated according to the following equation:

$$a_j(t+1) = a_j(t)(1-d) + \{net_j[\max - a_j(t)]\}\ if\ net_j > 0$$
$$\{net_j[a_j(t) - min)]\}\ if\ net_j \leq 0, \qquad \text{(A.1)}$$

where $net_j = \sum_i w_{ij}\, a_i\,(t) + \sum_i w_{ij}\, v_i\,(t) a_i(t)$ (A.2)

where $a_j(t)$ represents the activation of the unit at iteration . The constant parameter d (= 0.05) is the ate decay of activation for each unit at every cycle, *min* is the minimum activation (-1) and *max* is the maximum activation. Net_j is the valence and activation net input to a unit calculated based on the connection weight w_{ij} between unit i and j unit.

Valences of units are updated according to a similar equation:

$$v_j(t+1) = v_j(t)(1-d) + \{net_j[\max - v_j(t)]\}\ if\ net_j > 0$$
$$\{net_j[v_j(t) - min)]\}\ if\ net_j \leq 0, \qquad (A.3)$$

where $net_j = \sum_i w_{ij}\, v_i\,(t) a_i(t)$ (A.4)

where $v_j(t)$ represents the valence of the unit at iteration. The constant parameter d (=0.05) is the rate decay of activation for each unit at every cycle, *min* is minimum activation (- 1) and is the *max* maximum activation.

Appendix B. Defining the Social Network of Agents

Social similarity Δij between two agents i and j is defined as Euclidean distance d in m dimensions:

$$\Delta_{ij} = \sqrt{\sum_{m \in S} \left(\frac{S_{mi} - S_{mj}}{max\ d_m}\right)^2} \qquad (B.1)$$

where m is the number of socio-demographics factors; S_m is the socio-demographic variable under consideration and S_{mi} is the particular variable of an agent i. The similarity calculations are normalized by the maximum distance d_m observed within the agent population along the respective dimensions. Based on the similarity of two agents we define a social tie weight ∂ij for each pair:

$$\delta_{ij} = 1 - \left(\frac{\Delta_{ij}}{max\ \Delta}\right) \qquad (B.2)$$

The final probability that two agents form a social tie is additionally influenced by a stochastic factor R ranging from 0 to 1. Formally expressed:

$$if\ R < \delta_{ij} \qquad (B.3)$$

The resulting social network is static; i.e., social ties do not change over the course of one simulation run.

Table C1: Input and output parameter settings

Variable Type	Para-meter	Range or Value	Meaning	Input/ Output
HOTCO parameter				
Need units ($G_{1\text{-}8}$)				
	w_{ij}	-1 to +1	Facilitation weight between need unit and action unit ≙ cognitive representation to which degree a need is accomplished by a certain action	Input
	w_{ij}	-1 to +1	Valence weight between need unit and special valence unit ≙ valence of a specific need	Input
	p_i	-1 to +1	Priority weight between need unit and special unit ≙ priority of a need	Input
	a_i	-1 to +1	Activation of a need unit ≙ impact of a need on decision making	Output
	v_i	-1 to +1	Valence of a need unit ≙ intrinsic emotional valence of a need or action	Output
Action units ($A_{1\text{-}5}$)	w_{ij}	-1 to +1	Facilitation weight between need unit and action unit ≙ cognitive representation to which degree a need is accomplished by a certain action	Input
	w_{ij}	-1 to +1	Valence weight between action unit and special valence unit ≙ valence of a specific action	Input
	a_i	-1 to +1	Activation of an action unit ≙ indicates which option to choose	Output
	v_i	-1 to +1	Valence of an action unit ≙ emotional valence of the associated mode of transport	Output
Socio-demographic/ - economic parameters				
	A	18 to 69	Age of an agent	Input
	G	0,1	Gender of an agent	Input
	I	1 to 7	Income categories	Input
	E	1 to 5	Level of education	Input
	C	1 to 3.6	Standard of consumption (Otte, 2005)	Input
	M	1 to 4	Level of modernity (Otte, 2005)	Input
Further parameters				
	T	1 to 4	Different mobility types based on previous conducted cluster analysis	Input
	r	0 to 1	Social radius ≙ social range of an agent limiting the size of the personal network	Input
	X,Y	0.33 to 0.68	Geographic coordinates (latitude and longitude) assigned to postal codes	Input

Note: all input parameters were determined empirically based on our survey study (see main text).

The percentage values shown in Table D.1 and D.2 represent self-reported mean changes of transport-related attitudes resulting from positive and negative vignette statements emphasizing facts (Table D.1) or emotions (Table D.1) in an unpublished experiment (N = 480). These empirical values were used to model attitude change in the HOTCO networks representing InnoMind agents as a function of belief congruence between the sending and receiving agents: The values in Table D.1 indicate changes in the strength of the links between need and action nodes (means-ends communication; see explanations in the main text), while the values in Table D.2 indicate changes in the valence of the action nodes (emotional contagion; see main text).

Table D.1: Percentage factors of rational influence π for the information-receiving agent in means-ends communication

	Receivers facilitation weight w_{ij}				
Senders facilitation weight w_{ij}	$w_{ij} \geq .60$	$.20 \leq w_{ij} < .60$	$-.20 \leq w_{ij} < .20$	$-.60 < w_{ij} < -.20$	$w_{ij} \leq -.60$
$w_{ij} > .30$	π = +8.3%	π = +7.3%	π =+4.0%	π = -4.1%	π = -3.0%
$w_{ij} < -.30$	π = -0.3%	π = -0.6%	π = -1.3%	π = -0.3%	π = -2.0%

Table D.2: Percentage factors of emotional influence α for the information-receiving agent in contagion communication

	Receivers valence weight v_{ij}				
Senders valence weight v_i	$v_i \geq .60$	$.20 \leq v_i < .60$	$-.20 \leq v_i < .20$	$-.60 < v_i < -.20$	$v_i \leq -.60$
$v_i > .10$	α = +7.5%	α = +3.5%	α = +0.6%	α = -1.0%	α = -2.5%
$v_i < -.10$	α = +4.0%	α = +0.35%	α = -0.1%	α = -0.85%	α = -1.8%

9 Allgemeine Diskussion und Ausblick

Ist es möglich, das komplexe Zusammenspiel von psychologischen, interpersonalen sowie sozialen Faktoren und Mechanismen im Zuge gesellschaftlicher Transformationsprozesse in einem theoretisch und empirisch plausiblen Modell zu erfassen? In dieser Dissertation habe ich unter Rückgriff auf etablierte kognitionswissenschaftliche, sozialpsychologische und soziologische Theorien und umfassende empirische Forschung gezeigt, dass man diese Frage mit einem Ja beantworten könnte. Der Ausgangspunkt des von mir entwickelten Ansatzes ist das Prinzip der emotionalen Kohärenz, dem zufolge Menschen bei der Informationsverarbeitung und Einstellungsbildung nach der Widerspruchfreiheit kognitiver und emotionaler Repräsentationen streben. Basierend auf diesem Prinzip und mithilfe empirischer Untersuchungen wurde zunächst ein neuronales Netzwerkmodell der Einstellungen gegenüber Verkehrsmitteln entwickelt. In einem weiteren Schritt konnte ich in einer experimentellen Untersuchung zeigen, dass die im Kontext interpersonaler Kommunikation auftretenden Tendenzen motivierter Informationsverarbeitung durch das Einstellungsmodell erklärt werden können, das um eine Lernfunktion erweitert wurde. Darüber hinaus lieferten die Ergebnisse einer repräsentativen Befragungsstudie zu Mobilitätsinnovationen wichtige Erkenntnisse über die Einstellungen gegenüber konventionellen und neuen Formen der Mobilität sowie die Bedeutung affektiver Wahrnehmungen für die Nutzungsintentionen umweltfreundlicher Mobilitätsangebote. Schließlich wurden die theoretischen und empirischen Befunde in das agentenbasierte Modell *InnoMind* integriert und verschiedene Interventionsszenarien zur Förderung nachhaltiger Mobilität wurden analysiert.

In dieser allgemeinen Diskussion möchte ich zunächst zusammenfassend erörtern, wie die in den Kapiteln 5 bis 8 dargestellten Studien zur Beantwortung der drei zentralen Forschungsfragen sowie den jeweiligen Unterfragen beigetragen haben. Zweitens diskutiere ich die Einschränkungen und offenen Fragen, die berücksichtigt werden müssen, um den in dieser Dissertation vorgeschlagenen Modellansatz weiterzuentwickeln. Schließlich weitet sich die Perspektive, indem ich die Implikationen für die Forschung und für praktische Kontexte bespreche.

9.1 Diskussion der Forschungsfragen

1. Forschungsfrage: Welchen Einfluss hat die Verwendung emotionaler Sprache im Kontext persuasiver Kommunikation auf die Informationsverarbeitung von Menschen?

Die erste Forschungsfrage wurde im Rahmen einer empirisch-experimentellen Studie dieser Arbeit untersucht (Studie 1) und in folgende Unterfragen unterteilt:

a. Wird die Tendenz zur motivierten Informationsverarbeitung (motivierte Kognition) durch den emotionalen Gehalt persuasiver Kommunikation beeinflusst?

Die aus früheren Forschungsarbeiten bekannten Verzerrungseffekte motivierter Kognition werden durch die Studie reproduziert (z. B. Bayes, Druckman, Goods, & Molden, 2020; Bolsen, Druckman, & Cook, 2014). Dies zeigte sich einerseits in der Bewertung der Informationsquellen und andererseits in dem subjektiv wahrgenommenen Einfluss der Aussagen auf die eigene Haltung. Die Kompetenz und die Beliebtheit der fiktiven Verfasser sowie die Überzeugungskraft der präsentierten Aussagen fiel umso positiver aus, je deutlicher die Aussagen mit den ursprünglichen Einstellungen der Befragten übereinstimmten. Weiterhin liefert das Experiment Evidenz dafür, dass motivierte Kognition Meinungsunterschiede verstärken kann, indem Personen mit sehr festen Überzeugungen ihre Einstellungen in die entgegengesetzte Richtung der persuasiven Argumente verstärken (*Backfire Effect*), womit das Experiment Ergebnisse aus vergleichbaren Experimenten bestätigt (z. B. Hart & Nisbet, 2012; Zhou, 2016).

Die Tendenz zur verzerrten Informationsverarbeitung wurde durch den Grad der Emotionalität persuasiver Botschaften beeinflusst. Diese Unterschiede zeigten sich jedoch nur im Hinblick auf die Bewertungsmerkmale der Verfasser der Nachrichten und nicht bezüglich der wahrgenommenen meinungsverändernden Wirkung der Apelle. Im Vergleich der drei experimentell variierten Nachrichtentypen wurde deutlich, dass Überzeugungsversuche, die rationale Argumente mit emotionalen Komponenten verknüpfen, am stärksten motivierte Kognition evozierten. Bei Appellen hingegen, die argumentativ und unemotional formuliert waren, war diese Tendenz am geringsten ausgeprägt. Zudem zeigte sich interessanterweise in der differenzierten Betrachtung positiver und negativer Überzeugungsversuche, dass die Valenz der Aussagen einen entscheidenden Effekt auf die Glaubwürdigkeit und Überzeugungskraft der Appelle sowie auf die Tendenz zur motivierten Kognition hat. Der Verzerrungseffekt war bei den positiven Botschaften deutlich stärker ausgeprägt als bei negativen. In der Gesamtbetrachtung bestätigen die Resultate die in vorherigen Studien hervorgehobene Bedeutung emotionaler Aspekte persuasiver Kommunikation (z. B. Petty & Briñol, 2015) und zeigen darüber hinaus die noch größere Relevanz emotionaler Valenz für die Tendenz zu motivierter Kognition.

b. Können die experimentellen Ergebnisse mithilfe eines PCS-Modells dyadischer Kommunikation reproduziert und erklärt werden?

Um diese Frage zu beantworten, wurden sowohl die Einstellungen der Experimentteilnehmer:innen als auch die persuasiven Aussagen (Vignettentexte) in Form von Parallel-Constraint-Satisfaction(PCS)-Modellen emotionaler Kohärenz repräsentiert (vgl. Paul Thagard, 2006).

Strukturell waren die PCS-Modelle für beide an der Kommunikation beteiligten Akteure – das heißt Sender und Empfänger – gleich. Die Unterschiede lagen in der Parametrisierung der Gewichtungen der Netzwerkkanten. Um den Einfluss der persuasiven Appelle auf die den Einstellungen zugrunde liegenden mentalen Strukturen zu untersuchen, wurden die fiktiven Überzeugungsversuche zwischen den PCS-Modellen der jeweiligen Sender und Empfänger simuliert. Wesentlicher Unterschied zu früheren Ansätzen (z. B. Simon et al., 2015) liegt in der rigorosen und detailgenauen Umsetzung und Parametrisierung der empirisch-experimentellen Prozesse beziehungsweise Daten in den Modellen.

Die Theorie der emotionalen Kohärenz geht von einem zentralen Mechanismus der Kohärenzmaximierung mentaler Repräsentation im Zuge der Informationsverarbeitung und Einstellungsbildung aus. Gemäß dieser Annahme werden sowohl bestehende Repräsentationen als auch neue Informationen durch das affektiv-kognitive System derart modifiziert, dass deren Elemente weitestgehend kohärent und widerspruchsfrei repräsentiert werden und in Folge eine Einstellungs- oder Entscheidungsoption favorisiert wird. In einem ersten Schritt konnte gezeigt werden, dass zwischen den ursprünglichen empirisch gemessenen Einstellungen der Teilnehmer:innen und der mittels PCS-Modell berechneten Kohärenz der zugrunde liegenden mentalen Strukturen eine umgekehrt u-förmige Beziehung herrscht. Das bedeutet, dass stark positive oder negative Einstellungen ein hohes Maß an Kohärenz aufweisen. Interessanterweise ist das Kohärenzniveau für sehr positive Einstellungen höher als bei sehr negativen Einstellungen, sodass die im Experiment identifizierten Valenzunterschiede motivierter Kognition auf diese Asymmetrie zurückgeführt werden können. Demnach neigen Menschen mit einem hohen Grad an mentaler Kohärenz, wie theoretisch vorhergesagt, stärker dazu, Informationen verzerrt zu bewerten.

c. Welchen Effekt haben die unterschiedlichen Formen persuasiver Kommunikation auf die den Einstellungen zugrunde liegenden mentalen Strukturen?

In einem weiteren Schritt wurden die mit den wahrgenommenen Einstellungsveränderungen einhergehenden Modifikationen mentaler Strukturen modelliert. Für die nach den drei untersuchten Formen persuasiver Kommunikation spezifisch modellierten und getrennt durchgeführten Analysen zeigten sich spezifische Anpassungen der neuronalen Netzwerkparameter. Ausmaß und Qualität der Modifikationen mentaler Strukturen unterschieden sich signifikant. Besonders deutlich wurden die Abweichungen im Vergleich der rein emotionalen mit den beiden übrigen Argumentationsformen – der rationalen und kombinierten Argumentation. Die im Sinne motivierter Kognition erwarteten Verzerrungseffekte, im Besonderen die sogenannten Backfire-Effekte, wurden unter der emotionalen Persuasion am sichtbarsten. Das Ausmaß der Verzerrung ist unter der kombinierten Bedingung (emotional-rationale Argumentation) am stärksten. Weiterhin unterschieden sich die in Folge der Modifikation affektiv-kognitiver Strukturen berechneten Kohärenzniveaus zwischen den drei Modelltypen. Während die Kohärenz unter der rationalen Argumentation beinahe unverändert bleibt, weist diese für die vornehmlich emotionale und die kombinierte emotional-rationale Argumentation ein zunehmendes Niveau auf. Diese Resultate belegen die im Zuge von Einstellungsänderungen theoretisch vorhergesagte Reevaluation und Restrukturierung affektiv-kognitiver Elemente im Sinne der Kohärenzmaximierung und verdeutlichen die in diesem Zusammenhang besondere Bedeutung emotionaler Informationen und Strukturen.

2. Forschungsfrage: Welche Bedeutung haben affektive Wahrnehmungen von Verkehrsangeboten für die Akzeptanz und Bereitschaft zur Verhaltensveränderung im Mobilitätsbereich?

Der zweiten Forschungsfrage wurde im Rahmen einer umfangreichen deutschlandweiten Befragungsstudie nachgegangen (Studie 2), die in folgende Unterfragen unterteilt wurde:

a. *Welchen Einfluss haben die Kenntnisse, Einstellungen und Bewertungen der Bürgerinnen und Bürger in Deutschland gegenüber konventionellen und neueren Formen der Mobilität auf die Nutzungsbereitschaft der Verkehrsmittel?*

Im Zuge der Transformation des Verkehrssystems hin zu einer umweltfreundlicheren und nachhaltigeren Mobilität ist in den letzten Jahren eine immer größer werdende Vielfalt an technologischen und sozialen Innovationen entstanden. Im Rahmen der in dieser Arbeit durchgeführten bevölkerungsrepräsentativen Studie wurden erstmals die Kenntnisse, Einstellungen und affektiven Reaktionen der Bürger:innen gegenüber diesem bereiten Spektrum an Optionen gemeinsam untersucht. Die Ergebnisse zeichnen ein klares Bild einer Gesellschaft, die den konventionellen Verkehrsmitteln – insbesondere den Autos mit Verbrennungsmotor – noch immer den Vorzug gibt. Autos wurden im Hinblick auf die Kriterien Flexibilität, Zeiteffizienz und Komfort am attraktivsten bewertet. Das Fahrrad erfuhr hohe Zustimmung und wird insbesondere aufgrund seiner Umweltfreundlichkeit und Kosteneffizienz geschätzt. Interessanterweise wurde nach dem Pkw unter den konventionellen Formen der Mobilität die Fortbewegung zu Fuß besonders geschätzt. Die Menschen sehen dabei vor allem ihre Bedürfnisse nach einer umweltfreundlichen und kosteneffizienten Mobilität erfüllt, aber verbinden damit auch ein positives körperliches Erlebnis und den Ausdruck ihres Lebensstils. Der öffentliche Nahverkehr schnitt in allen Bewertungskategorien am schlechtesten ab und fand die geringste Zustimmung.

Bei neueren Fortbewegungsformen verfügt die Mehrheit der Befragten nur über eingeschränkte Kenntnisse und hat in der Regel damit noch keine eigenen Erfahrungen machen können. Elektrisch betriebene Pkws und Fahrräder sind in der Bevölkerung bekannter als unterschiedliche Formen autonomen Fahrens oder des Carsharings. Die Einschätzungen hinsichtlich instrumenteller Attribute wie Zeit- und Kosteneffizienz oder Sicherheit sind aufgrund unvollständigen Wissens und unzureichender eigener Erfahrungen mit bedeutsamen Unsicherheiten verbunden.

Die affektive Wahrnehmung der Verkehrsmittel stellt in diesem Kontext einen wichtigen Prädiktor für die Akzeptanz der neuen Verkehrsangebote dar. Im Vergleich zu den übrigen Mobilitätsinnovationen wurden Elektroautos und -fahrräder am positivsten bewertet, während die verschiedenen Varianten autonomen Fahrens und des Carsharings neutral bis negativ eingeschätzt wurden. Die zusätzlich erhobenen Nutzungsintentionen der Mobilitätsinnovationen bestätigen die vorhergesagte Handlungsrelevanz der affektiven Bedeutung der untersuchten Mobilitätsoptionen. In der Gesamtbetrachtung bestätigen die Ergebnisse die aus anderen empirischen Analysen bekannte dominante Rolle konventioneller Pkws in der heutigen Mobilitätslandschaft in Deutschland (vgl. Nobis, 2020). Zugleich verdeutlichen die Resultate, dass für die Verlagerung dieses Verkehrs im Besonderen das klassische Fahrrad und die Fortbewegung zu Fuß, zumindest in Städten und auf kurzen Wegen, als attraktive Alternativen angesehen werden. Unter den neueren Technologien stehen die Menschen insbesondere Elektrofahrzeugen recht aufgeschlossen gegenüber, die jedoch aufgrund ihrer vergleichsweise hohen Anschaffungskosten nur für bestimmte gesellschaftliche Gruppen als Fortbewegungsalternative infrage kommen. Die abnehmende emotionale Bindung zum eigenen Pkw in der jüngeren Generation liefert erste Anzeichen für einen Mobilitätswandel in Teilen der Bevölkerung, der beispielsweise durch zielgruppengerechte Carsharingangebote unterstützt werden kann.

b. Können auf Basis der affektiven Bewertungen von Verkehrsmitteln Zielgruppen definiert werden, die sich hinsichtlich ihres aktuellen und intendierten Verkehrsverhaltens unterscheiden?

Maßnahmen des sozialen Marketings, wie zum Beispiel zielgruppenspezifische Informationskampagnen, können das Bewusstsein für nachhaltige Mobilität fördern (Thøgersen, 2014). Zu diesem Zweck wurde auf Basis der affektiven Wahrnehmungen aller untersuchten Verkehrsmittel eine neue theoretisch begründete Mobilitätstypologie der deutschen Bevölkerung erstellt. Mithilfe von Clusteranalysen wurden sechs Personengruppen identifiziert, die sich hinsichtlich ihrer Affektmuster deutlich unterscheiden und sich zur Ableitung von (Informations-)Maßnahmen zur Steigerung der Akzeptanz neuer Mobilitätsangebote eignen. Zum Zweck der Validierung wurden die Gruppen anhand verschiedener soziodemografischer Einstellungs- und Überzeugungs- sowie Verhaltensmerkmale verglichen. Die von den Teilnehmer:innen berichteten Mobilitätsverhalten und -präferenzen sind in hohem Maße mit den gruppenspezifischen affektiven Wahrnehmungsmustern der Verkehrsoptionen assoziiert. Zudem konnte gezeigt werden, dass die Segmente hinsichtlich distaler Merkmale (z. B. Soziodemografie, Werte und politische Orientierung) relevante Unterschiede aufweisen. Beispielsweise befinden sich in der Gruppe der „umweltorientierten Meinungsführer" tendenziell Menschen, die bei der Verkehrsmittelwahl besonders Aspekte der Umweltfreundlichkeit achten und sich mehrheitlich mit linksgerichteten Parteien identifizieren. Personen dieses Segments äußern generell die höchste Nutzungsbereitschaft neuer Mobilitätsformen mit einer besonderen Vorliebe für Carsharingangebote.

In der Zusammenschau bestätigen Resultate den bereits in früheren Arbeiten identifizierten Zusammenhang zwischen emotional-affektiven Bewertungen von Handlungsoptionen und (intendiertem) Verkehrsverhalten (z. B. Schuitema et al., 2013). Das in dieser Arbeit gewählte Vorgehen schließt an frühere psychografische Segmentierungsansätze in der psychologisch orientierten Verkehrsforschung an und adressiert darüber hinaus die vielfach geäußerte mangelnde theoretische Fundierung von empirisch entwickelten Typologien (vgl. Marcel Hunecke, 2015). In Anlehnung an den theoretischen Rahmen der Affektsteuerungstheorie (*Affect Control theory,* Heise, 2007) konnte gezeigt werden, dass implizites kulturelles Wissen, das in affektiven Bedeutungen verbaler Konzepte verankert ist, zur Identifikation und Charakterisierung von spezifischen Mobilitätssegmenten in der Gesellschaft geeignet ist. Der für die Mobilitätsforschung neuartige Ansatz stellt eine sparsame und flexible Vorgehensweise dar, um insbesondere im Kontext des Mobilitätswandels, der durch mangelndes Wissen und fehlende Erfahrungen in der Bevölkerung charakterisiert ist, effektive und zielgruppenspezifische Maßnahmen zur Veränderung von Verkehrsverhalten entwickeln zu können.

c. Welche zielgruppenspezifischen Interventionen lassen sich auf Grundlage des gewählten Ansatzes ableiten?

Ausgehend von der theoretischen Annahme, dass Menschen in ihrem Verhalten durch die affektive Bedeutung von Identitäten, Objekten und Handlungsoptionen maßgeblich beeinflusst werden und dabei die Tendenz haben, affektive Dissonanzen zu vermeiden, konnten auf Basis der entwickelten Typologie Empfehlungen für die Entwicklung zielgruppenspezifischer Kommunikationsmaßnahmen abgeleitet werden. So sind zum Beispiel Mobilitätskampagnen, die die Nutzung des öffentlichen Personennahverkehrs (ÖPNV) propagieren, mit dessen affektiver Wahrnehmung als unangenehmer (E), mit niedrigem Status verbundener (P) und langsamer Verkehrsträger (A) – insbesondere unter den Mitgliedern der Segmente der „komfortorientierten Individualisten" und der „risikoaversen Traditionalisten" – nicht konsistent. Folglich werden diese Verkehrsteilnehmer:innen dazu neigen, entsprechende Informationen zu ignorieren und abzulehnen. Wirkungsvoller hingegen sind Kampagnen, die zur Nutzung alternativer Verkehrsmittel anregen, die in den jeweiligen Subgruppen affektiv positiv konnotiert sind: Für „ökologisch orientierte Meinungsführer“ ist dies beispielsweise die Fortbewegung zu Fuß, mit dem (Elektro-)Fahrrad oder dem batterieelektrischen Auto; für „innovationsorientierte Progressive“ die Nutzung von Elektroautos mit Hybrid-, batterieelektrischem oder Brennstoffzellenantrieb oder das Zufußgehen; für „kostenbewusste Pragmatiker“ das konventionelle Fahrrad oder Elektrofahrrad; für „komfortorientierte Individualisten“ die Fortbewegung zu Fuß, mit dem (Elektro-)Fahrrad oder dem Brennstoffzellenauto; für „gemeinwohlorientierte Stadtbewohner“ die Nutzung von (Elektro-)Fahrrad oder flexiblen Carsharingangeboten und schließlich für „risikoaverse Traditionalisten“ das Zufußgehen und das Mit-dem-Fahrrad-unterwegs-Sein.

Die sprachbasierte Konzeptualisierung und die multidimensionale Metrik (Evaluation, Potency, Activity; EPA) des gewählten Ansatzes erlauben es, konkrete quantitative Schätzungen über die affektive Konsistenz der in Kampagnen dargebotenen Informationen und über die jeweiligen Repräsentationen der Subgruppen vorzunehmen. Mithilfe experimenteller Untersuchungen könnten die Effekte derartiger zielgruppenspezifischer Kampagnen zur Veränderung von Verkehrsverhalten im Labor wie auch in realen Situationen evaluiert werden.

3. Forschungsfrage: In welcher Weise können die psychologischen und sozialen Prozesse sowie politischen Einflüsse der Einstellungsbildung gegenüber Mobilitätsinnovationen in einem agentenbasierten Modell psychologisch plausibel und problemadäquat abgebildet werden?

Die letzte Forschungsfrage wurde mithilfe von zwei Simulationsstudien (Studie 3 und Studie 4) untersucht und in folgende Unterfragen unterteilt.

a. *Welche Modellstruktur und Konzepte sind geeignet, um Einstellungsdynamiken im Mobilitätsbereich psychologisch plausibel und realistisch zu modellieren?*

Der Fokus des agentenbasierten Modells *InnoMind* liegt auf der Analyse individueller Informationsverarbeitung und Einstellungsbildung sowie den durch informative Einflüsse entstehenden Dynamiken in sozialen Netzwerken. Fragen, beispielsweise zu den Auswirkungen von infrastrukturellen, räumlichen oder technischen Faktoren auf Mobilitätspräferenzen, überlasse ich künftiger Forschung. Die Modellstruktur baut auf den in Studie 1 und 2 dargestellten und diskutierten theoretischen Überlegungen und Konzepten auf. Die mentalen Repräsentationen der Agenten über unterschiedliche Verkehrsmittel stellen den zentralen Bestandteil des Modells dar. Die entsprechenden Kognitionen und Emotionen wurden in Form von künstlichen neuronalen Netzwerken modelliert. Die Knoten in diesen Netzwerken repräsentieren verschiedene Einstellungs- und Entscheidungselemente, das heißt konkrete Bedürfnisse bei der Verkehrsmittelwahl, Handlungsoptionen und deren jeweilige emotionale Valenz. Die Kanten zwischen diesen Netzwerkknoten stellen die kognitiven Überzeugungen über die Eignung eines Verkehrsmittels, die individuellen Bedürfnisse zu erfüllen, sowie die affektiven Bedeutungen der Verkehrsmittel und Bedürfnisse dar. Die mentale Architektur ist für alle Agenten gleich und die Einstellungsheterogenität in der Bevölkerung wird durch die Variation der Kantengewichte abgebildet. Informationen aus dem sozialen Umfeld und zu politischen Kampagnen werden auf Basis der mentalen Modelle (re-)interpretiert und über einen Lernprozess werden Einstellungen oder Entscheidungen potenziell verändert. Die in diesem Zusammenhang implementierte Lernfunktion wurde auf Basis der in Studie 1 durchgeführten Arbeiten empirisch geschätzt.

Die informativen Einflüsse im sozialen Netzwerk werden durch bidirektionale Kommunikation zwischen Agenten simuliert. Dabei werden die aus den Zwei-Prozess-Theorien der Persuasionsforschung bekannten kognitiven (Überzeugungen, Argumente) und affektiven (Emotionen) Elemente beidseitig ausgetauscht. Welche Aspekte von Agenten kommuniziert werden, hängt von der individuellen Salienz der Bedürfnisse (das heißt deren Wichtigkeit) ab. Die Auswahl der Gesprächspartner ist nicht beliebig, sondern kann nur innerhalb bestehender sozialer Strukturen beziehungsweise Netzwerke erfolgen. Das soziale Netzwerk für die gesamte Agentenpopulation wird auf Basis des Homophilie-Prinzips (Wahlhomophilie) und der räumlichen Nähe (induzierte Homophilie) während des Modellsetups erstellt und bleibt im Verlauf der Simulation unverändert.

Zur Simulation politischer Kampagnen und Maßnahmen wurde eine weitere Ebene, die eines sogenannten Medienagenten, eingeführt. Die Architektur des Medienagenten entspricht den neuronalen Netzwerkstrukturen der virtuellen Verkehrsteilnehmer:innen in *InnoMind*. Politische Interventionen können somit in ihrer konkreten Wirkung auf spezifische Elemente der den Einstellungen und Entscheidungen zugrunde liegenden Strukturen untersucht werden. So würde beispielsweise die Simulation einer Kaufprämie für E-Autos lediglich die individuellen Überzeugungen der Kosteneffizienz von E-Autos modifizieren und alle übrigen mentalen Elemente unberührt lassen. Dieses Vorgehen bietet die Möglichkeit, die voraussichtlichen Effekte einer großen Bandbreite und Kombination von Maßnahmen, aber auch deren konkrete Ausgestaltung zu modellieren. Weiterhin können durch die Auswahl der in die Kampagnen einbezogenen Agenten zielgruppenspezifische Analysen realisiert werden.

In *InnoMind* wurden demnach mehrere für die einzelnen Modellebenen spezifische theoretische Ansätze integriert, um somit ein psychologisch und soziologisch plausibles sowie für praktische Problemstellungen geeignetes Modell zur Verfügung zu stellen.

b. In welcher Weise können die empirischen Ergebnisse in die Modellstruktur integriert werden?

Eines der zentralen Ziele der Arbeit war es, das Modell *InnoMind* auf eine umfassende empirische Basis zu stellen. Unter Rückgriff auf die im Rahmen des Forschungsprojekts INNO-SIM (BMBF, 2010-2013) und in Studie 1 gewonnenen Ergebnisse konnte dies realisiert werden (vgl. Wolf & de Haan, 2013). In dem Projekt INNO-SIM wurde mit einem Mixed-Methods-Ansatz gearbeitet, das heißt, es wurden in dem Forschungsvorhaben qualitative und quantitative Methoden kombiniert. In einem ersten Schritt wurden dabei in einer Reihe von Fokusgruppen unter anderem die im Alltag relevanten Entscheidungskriterien der Verkehrsmittelwahl untersucht. Die Ergebnisse lieferten die Grundlage für die zentralen Elemente der Einstellungs- und Entscheidungsstruktur der Agenten – die Mobilitätsbedürfnisse, Handlungsoptionen und deren affektiven Bedeutungen. Von diesen Erkenntnissen ausgehend wurde eine für die Berliner Bevölkerung repräsentative Onlinebefragung zu den kognitiven und affektiven Einstellungen gegenüber verschiedenen Verkehrsmitteln durchgeführt. Die Konzeption und der Inhalt der Befragung orientierten sich einerseits an den Ergebnissen der Fokusgruppen und andererseits an den für die Modellierung benötigten Parametern. Die Befragungsergebnisse lieferten die unmittelbare empirische Datengrundlage der Simulation, indem die befragten Personen mit ihren jeweiligen individuellen psychologischen und soziodemografischen Merkmalen in dem Modell virtuell nachgebildet wurden. Zur Parametrisierung der initialen PCS-Netzwerke mussten die Befragungsdaten in für die Modellierung geeignete Zahlenbereiche übersetzt werden (siehe Abschnitt Methoden in Studie 3 und 4). Zuletzt wurden die im Zuge der Simulation sozialer Einflüsse berechneten Einstellungsveränderungen mithilfe des in Studie 1 durchgeführten Vignettenexperiments geschätzt.

Zusammenfassend kann festgestellt werden, dass die Integration der empirischen Ergebnisse in das theoretische Modell nur dadurch so detailreich und exakt gelingen konnte, da die Konzeption der empirischen Studien auf Grundlage der Modellstruktur und unter Kenntnis der in diesem Kontext benötigten Parameter erfolgte. Das Vorgehen stellt dennoch ein anschauliches Beispiel für ein umfassendes und integratives Konzept der empirischen Modellentwicklung dar. Dabei ist diese Art der Initialisierung und Parametrisierung des Modells *InnoMind* nicht alternativlos. So konnte im Rahmen eines Konferenzbeitrags gezeigt werden, dass auch aggregierte, nicht themenspezifischen Datensätzen wie zum Beispiel Wahlergebnisse geeignet sind, um eine robuste Parametrisierung des Modells vorzunehmen (vgl. Wolf, Röhr, & Schröder, 2017).

c. Welche voraussichtlichen Einstellungsänderungen und Dynamiken ergeben sich aufgrund sozialer Einflüsse in der Bevölkerung?

Zur Untersuchung dieser Frage wurde nach der Parametrisierung und Initialisierung des Modells das Referenzszenario berechnet. Dabei wurde die Kommunikation über mobilitätsspezifische Überzeugungen und Emotionen zwischen den Personen beziehungsweise Agenten simuliert. Die Effekte dieses sozialen Einflusses auf die Verkehrsmittelpräferenzen der Agenten wurden für vier unterschiedliche Subgruppen, sogenannte Mobilitätstypen, getrennt analysiert. Die Simulationsergebnisse zeigen, dass die Einstellungsprofile der jeweiligen Mobilitätstypen durch die interpersonale Kommunikation generell moderat beeinflusst werden. Diese Ergebnisse werden auch durch zahlreiche empirische Untersuchungen zur Wirkung sozialen Einflusses auf Mobilitätseinstellungen und -verhalten bestätigt (vgl. Metastudie von Pettifor, Wilson, Axsen, Abrahamse, & Anable (2017)). Im zeitlichen Verlauf der Simulation wurden jedoch auch Unterschiede hinsichtlich der Sensibilität gegenüber sozialen Einflüssen zwischen den Subgruppen sichtbar. Beispielsweise führte in der Gruppe der „komfortorientierten Individualisten" soziale Kommunikation zu einer leichten Abnahme der Präferenzen für Autos mit Verbrennungsmotoren zugunsten von E-Autos, während unter den „umweltorientierten Meinungsführern" der Anteil von Personen, die den öffentlichen Personennahverkehr bevorzugen, zugunsten der Nutzung von Carsharing zurückgeht. Diese Befunde unterstreichen die Wichtigkeit, die Heterogenität der Akteure und sozialen Gruppen bei der Analyse sozialer Dynamiken zu berücksichtigen.

d. *Welche voraussichtliche Wirkung haben politische Maßnahmen zur Förderung von Elektromobilität in Berlin und welche Schlüsse lassen sich daraus für die Gestaltung und Implementierung von Interventionen ziehen?*

Die Auswahl der analysierten politischen Interventionen orientierte sich an dem von der nationalen Plattform E-Mobilität vorgeschlagenen Maßnahmenmix zur Förderung E-Mobilität (siehe Nationale Plattform Elektromobilität, 2011). Es handelt sich dabei um zwei ökonomische Instrumente, der Einführung einer Kaufprämie und der Kfz-Steuerbefreiung von E-Autos, und um eine ordnungsrechtliche Maßnahme, der Einführung von Verkehrszonen in Innenstädten, die ausschließlich von E-Autos befahren werden dürfen. Dabei ist zu beachten, dass deren Implementierung in das Modell in Form von spezifischen Informationskampagnen erfolgte. Das bedeutet, dass damit nicht bestimmte Merkmale der externen Umwelt der Agenten, zum Beispiel die Fahrzeiten in Innenstädten, verändert wurden, sondern vielmehr direkt die entsprechenden mentalen Repräsentationen der Agenten über E-Autos beeinflusst und modifiziert wurden. Analog zum Referenzszenario wurden die Szenarien für die vier Mobilitätstypen getrennt analysiert. Die Ergebnisse lieferten drei zentrale Erkenntnisse: Erstens: Die Fördermaßnahmen erhöhen generell, unabhängig von der spezifischen Ausgestaltung, insbesondere in den Teilen der Bevölkerung mit tendenziell ablehnender Haltung gegenüber E-Autos deren Akzeptanz. So steigt in allen Szenarien die Wechselbereitschaft in der Gruppe der sogenannten „kostenorientierten

Pragmatiker", die in dem Referenzszenario durch eine sehr niedrige Zustimmungsrate gekennzeichnet ist, deutlich stärker als in den Gruppen mit hohen Anteilen an E-Auto-Befürworter:innen. Zweitens: Die simulierte Wechselwirkung von sozialen Einflüssen und politischen Interventionen führt zu zielgruppenspezifischen, teilweise nichtlinearen, Dynamiken der Einstellungen gegenüber E-Autos. Dies zeigt einerseits, dass die Wirksamkeit der Anreize durch die spezifischen Einstellungs- und Bedürfnisprofile der jeweiligen Mobilitätstypen beeinflusst wird. Andererseits legen die Resultate nahe, dass die Kommunikation in sozialen Netzwerken die Effekte der Interventionen sowohl verstärken als auch abschwächen können. Diese Befunde werden auch durch zahlreiche empirische Studien im Bereich der sozialen Netzwerkforschung gestützt (vgl. Centola, 2021). Drittens: Ordnungspolitische Maßnahmen, wie die Einführung von ausschließlich von E-Autos zu befahrenden Verkehrszonen in Innenstädten, können vergleichsweise ähnlich starke beziehungsweise stärkere Effekte auf die Nutzungsbereitschaft von E-Fahrzeugen evozieren, wie dies durch monetäre Anreize der Fall ist.

Einschränkend ist darauf hinzuweisen, dass die Ergebnisse nicht auf ganz Deutschland verallgemeinert werden können, da sich die Studien ausschließlich auf das Bundesland Berlin bezogen haben. Dennoch liefern die Analysen wichtige Hinweise dafür, dass eine zielgruppenspezifische und bedürfnisorientierte Gestaltung und Kommunikation der Interventionsmaßnahmen deren Effektivität entscheidend erhöhen kann.

e. *Welche Bedeutung haben bedürfnisorientierte Informationskampagnen über Carsharing auf die Nutzungspräferenzen des Verkehrsangebots*?

Zur Untersuchung dieser Fragestellung wurde das ABM *InnoMind* verwendet. Die empirisch basierte Parametrisierung und die Struktur des Modells entsprechen dem Vorgehen in Studie 3. Im Gegensatz zu der in Studie 3 analysierten Wirksamkeit politischer Fördermaßnahmen von E-Mobilität wurde in dieser Studie der aus der Sozialpsychologie bekannte Ansatz des „goal-framings" gewählt (vgl. Levin, Schneider und Gaeth, 1998), um potenziell erfolgreiche Kampagnenstrategien für die Nutzung von Carsharing zu identifizieren. Die acht simulierten Kampagnenszenarien unterscheiden sich folglich durch die Betonung bestimmter positiver Konsequenzen der Nutzung von Carsharing für psychologische Bedürfnisse und Ziele dieser Verkehrsmittelwahl. Die Simulationsergebnisse des Referenzszenarios zeigen, dass soziale Einflüsse, ohne die zusätzliche Implementierung von Informationskampagnen, zu einem moderaten Anstieg der Präferenzen von Carsharing führen können. Aus den Ergebnissen der Kampagnenszenarien lässt sich generell ein bedeutsamer positiver Effekt auf die Nutzungsbereitschaft von Carsharing ablesen. Die Wirkungen der einzelnen Kampagnenframings unterscheiden sich dabei deutlich. Die effektivsten Interventionen sind Kampagnen, die die Vorteile von Carsharing hinsichtlich der gesteigerten Flexibilität sowie Sicherheit und der Reduzierung von Stress hervorheben. Weiterhin verdeutlichen die Resultate, dass durch die Interventionen die intendierte Verkehrsverlagerung vom motorisierten Individualverkehr auf Carsharingangebote gefördert werden kann.

Zusammengefasst deuten die Ergebnisse darauf hin, dass die Art und Weise, wie Informationskampagnen über Carsharing formuliert werden beziehungsweise welche bedürfnisorientierten Nutzungsaspekte sie betonen, einen großen Einfluss darauf hat, wie Menschen darauf reagieren. Diese Erkenntnisse werden durch zahlreiche empirische Untersuchungen zu Framingeffekten im Verkehrsbereich (Raux, Chevalier, Bougna, & Hilton, 2020) sowie in verschiedenen anderen Handlungsfeldern bestätigt (Chong & Druckman, 2007; Keren, 2010; Tversky & Kahneman, 1981). Diese Form der Intervention stellt neben finanziellen und ordnungspolitischen Maßnahmen ein wichtiges komplementäres Instrumentarium zur Förderung nachhaltiger Mobilität dar. Zudem konnte anhand der Anwendung des ABM *InnoMind* in dieser Studie gezeigt werden, dass das Simulationsmodell zur Untersuchung unterschiedlicher Fragestellungen flexibel und zeiteffizient angepasst werden kann.

9.2 Einschränkungen und offene Fragen

Der im Rahmen dieser Dissertation entwickelte Ansatz stellt ein umfassendes theoretisch und empirisch fundiertes Instrument zur Analyse von Einstellungs- und Entscheidungsänderungen in sozialen Systemen dar. Dennoch existieren einige Limitationen und offene Fragen, um den Ansatz weiterzuentwickeln. Diese beziehen sich im Wesentlichen auf drei Aspekte. Erstens: Das Verfahren berücksichtigt derzeit nicht den Einfluss weiterer für Mobilitätseinstellungen und -verhalten relevanter externer Faktoren – zum Beispiel: Wie wirken sich Infrastruktur, persönliche Erfahrung oder der Einfluss anderer gesellschaftlicher Akteure auf die Einstellungen der Agenten aus? Zweitens: Zeitlich dynamische Aspekte müssen detaillierter untersucht werden – zum Beispiel: Wie zeitlich stabil sind die Überzeugungen und Affekte gegenüber Verkehrsmitteln, wie dynamisch sind soziale Kommunikationsnetzwerke im Themenfeld? Drittens: Es gibt einige methodische Punkte, die geklärt werden müssen – zum Beispiel: Wie valide sind die Simulationsergebnisse, wie können die Modellparameter ohne Fragebogendaten geschätzt werden?

9.2.1 Erweiterung externer Kontexte

Die Formalisierung von Einstellungen und Entscheidungen im Mobilitätsbereich konzentriert sich in dem Modell *InnoMind* auf die Ebenen der intrapsychischen Prozesse der Informationsverarbeitung und der Kommunikation in sozialen Netzwerken. Die Einstellungsbildung und Entscheidungsfindung ist im Allgemeinen, wie auch im speziellen Fall, selbstverständlich komplexer und umfasst im untersuchten Kontext diverse weitere externe Einflussfaktoren. So werden beispielsweise die Haltungen gegenüber Fortbewegungsmitteln auch durch verschiedene Merkmale der Verkehrsinfrastruktur bestimmt. Dies können Aspekte wie der Preis, die Verfügbarkeit oder Verlässlichkeit bestimmter Verkehrsmittel, die Existenz von Fahrradwegen und Schnellstraßen, die sich durch den Wohnort und die konkrete Lebenssituation ergebenden Mobilitätsbedarfe sowie verkehrsinduzierte Wegzeiten sein (vgl. Mattauch, Ridgway, & Creutzig, 2015). Die Erweiterung und Integration dieser Aspekte in das Modell *InnoMind* könnte durch die Implementierung erweiterter Repräsentationen auf der Makroebene (Umwelt) und Mikroebene (Agenten) erfolgen. Analog zu bestehenden Mikrosimulationsmodellen im Verkehrsbereich, zum Beispiel MATSim (Balmer et al., 2009), würde hierfür die verkehrliche Infrastruktur (z. B. Straßen, Verkehrsaufkommen) auf der Basis empirischer Quellen modelliert werden. Die Repräsentationen dieser Umwelt sowie die dort stattfindenden individuellen Erfahrungen und Lernprozesse der Agenten könnten durch die Erweiterung des bestehenden PCS-Netzwerkmoduls der Einstellungsobjekte (Verkehrsmittel) um ein analog konzipiertes PCS-Modul des Einstellungskontextes (Umwelt) erfolgen. Durch die geeignete Verbindung der Module wären damit kontextspezifische Präferenzen und Verhaltensregeln der Verkehrsmittelwahl ableitbar. Im Sinne der praktischen Anwendbarkeit und Nützlichkeit des Modells scheint diese Erweiterung vielversprechend. Weiterhin würde auch in theoretischer Hinsicht eine derartige Modifikation einen wichtigen Beitrag hin zu einem ganzheitlicheren Verständnis der Einstellungsbildung leisten (vgl. Albarracin & Shavitt, 2018). Ein entscheidender Schritt der Umsetzung wäre die Formalisierung der Wechselwirkung der kognitiven und affektiven Elemente der unterschiedlichen Informations- und Handlungsebenen der Agenten. In diesem Zusammenhang müsste auch spezifiziert werden, in welcher Weise die verschiedenen sozialen und umweltbedingten Einflüsse zu einer globalen Bewertung führen.

Ein zusätzlicher interessanter Erweiterungsaspekt wäre eine größere Differenzierung und Spezifizierung der Akteursgruppen und Informationsquellen im sozialen Netzwerk der Agenten. Die Einstellungen von Personen gegenüber (neuen) Mobilitätsangeboten werden in der Realität nicht nur, wie bislang im Modell angelegt, durch interpersonale Kommunikation im sozialen Umfeld oder politische Maßnahmen und Kampagnen beeinflusst. Werbung von Anbietern und Herstellern, die Art des Kommunikationsmediums, politische und gesellschaftliche (mediale) Debatten oder seltene und unerwartete Ereignisse tragen neben anderen Faktoren wesentlich zur Meinungs- und Einstellungsbildung bei. Neben der Ergänzung derartiger Informationsquellen in dem sozialen Netzwerk des Modells würde dies auch auf der individuellen Ebene eine wesentliche Modifikation erfordern – die mentale Repräsentation der eigenen und die der sozialen (Gruppen-)Identität anderer. Zahlreiche empirische Studien konnten zeigen, dass die Salienz der Identität von Informationsquellen einen bedeutsamen Einfluss auf die Art der

Informationsverarbeitung und -bewertung im Kontext von umwelt- und klimabezogenen Themen hat (Feldman & Hart, 2018; Guilbeaulta, Beckera, & Centola, 2018; Kahan et al., 2012). Zukünftige Forschung könnte sich darauf konzentrieren, mithilfe des Modells *InnoMind* die jeweiligen Konsequenzen und Implikationen der Diversifikation der Akteursgruppen auf Systemebene zu untersuchen.

9.2.2 Zeitliche Dynamiken

Gesellschaftliche Transformationsprozesse entfalten sich nicht linear, sondern entwickeln auf allen Systemebenen eigene zeitliche Dynamiken, die wichtige Auswirkungen auf das Gesamtsystem haben. Der im Rahmen dieser Dissertation entwickelte Modellansatz berücksichtigt einige dieser ebenenspezifischen und zeitlich varianten Aspekte nur unzureichend. Auf der individuellen Ebene betrifft dies die Stabilität der Handlungsziele und deren Prioritäten, die soziodemografischen Charakteristika, Verhaltensgewohnheiten und die Lerngeschwindigkeit der Agenten. Das in *InnoMind* verwendete PCS-Modell der Einstellungen und Entscheidungen geht davon aus, dass die Handlungsziele der Agenten in Anzahl und Priorität zeitlich konstant sind. Lernprozesse und Einstellungsänderungen finden dort lediglich durch die Modifikation bestehender Überzeugungen und Affekte in Folge sozialer Einflüsse innerhalb relativ kurzer Zeiträume statt. Empirische Befunde deuten jedoch darauf hin, dass mobilitätsbezogene Einstellungen und Entscheidungen zeitlich relativ stabil sind und individuelle Erfahrungen der Alltagsmobilität das Verhalten maßgeblich bestimmen (Agora Verkehrswende, 2020). Die Motive der Verkehrsmittelwahl und das Verkehrsverhalten selbst unterliegen, bedingt durch Lebensereignisse wie Arbeitsplatz- und Wohnortwechsel, Ruhestand, Geburt von Kindern, mittel- und langfristig bedeutsamen Veränderungen (Clark, Chatterjee, Melia, Knies, & Laurie, 2014). Zudem moderieren kontext- und persönlichkeitsbedingte Faktoren sowie soziodemografische Merkmale die Relevanz derartiger Ereignisse für jeden einzelnen Menschen (Kuhnimhof, Nobis, Hillmann, Follmer, & Eggs, 2019). Derzeit besteht nur wenig empirisches Wissen, wie die genannten Aspekte kurz-, mittel- und langfristig wechselwirken. Um die im Zuge des Wandels des Verkehrssystems zu unterschiedlichen Zeitpunkten stattfindenden Dynamiken besser zu verstehen und diesbezüglich politikrelevante Empfehlungen ableiten zu können, wäre es interessant, das Modell *InnoMind* in dieser Hinsicht zu erweitern. Im Wesentlichen geht es dabei um die Implementierung von drei Zeitskalen (kurz-, mittel-, langfristig) mit jeweils spezifischen zeitlich (un-)veränderlichen Faktoren und Mechanismen. Auf der ersten Zeitskala werden tagesspezifische Ereignisse (z. B. Verkehrsmittelnutzung, sozialer Einfluss, Kommunikation etc.) abgebildet. Auf der mittelfristigen Skala werden vor allem persönliche (z. B. Altern, bestimmte Lebensereignisse) sowie umweltbezogene Veränderungen (z. B. Transportkosten, alternative Optionen/Angebote), die im Zeitraum von einigen Monaten bis zu einem Jahr liegen, modelliert. Auf der dritten Zeitachse werden langfristige im Zeitraum mehrerer Jahre/Jahrzehnte stattfindende systemische Veränderungen (z. B. Wandel technologischer Regime, soziale Normen) repräsentiert. Die grundlegenden Einstellungs- und Entscheidungsmechanismen der Agenten würden dafür nicht verändert werden. Jedoch müssten zeitskalenspezifische Lernmechanismen implementiert und empirisch überprüft werden.

Auch auf der Ebene der sozialen Netzwerke sind strukturelle Veränderungen im zeitlichen Verlauf von Bedeutung. Die Qualität sozialer Beziehungen zwischen Menschen unterliegt kurz-, mittel- und langfristig stetigen Veränderungen (Sekara, Stopczynski, & Lehmann, 2016). Bisherige Forschung deutet darauf hin, dass soziale Dynamiken jedoch nicht zufällig stattfinden. So sind beispielsweise bei dyadischen Interaktionen klare Regelmäßigkeiten und Muster zu erkennen, die auf verschiedenen Zeitskalen auftreten (Saramäki & Moro, 2015). Empirische Studien konnten zudem durch die Beobachtung und Analyse der Interaktionen größerer Gruppen das Verständnis über die grundlegenden Strukturen sowie ihre zeitlichen Entwicklungen verbessern (z. B. Sapiezynski, Stopczynski, Lassen, & Lehmann, 2019; Sekara et al., 2016). Erste theoretische, modellbasierte Arbeiten konnten zeigen, dass zeitlich variable Konnektivitätsmuster einen bedeutsamen Einfluss im Kontext der epidemischen Verbreitung von Krankheiten haben (Nadini et al., 2018). Auf der Grundlage der wachsenden Anzahl umfassender Datensätze sowie formalisierter Modelle dynamischer Netzwerkbildung könnten die Auswirkungen zeitlich variabler Netzwerke auf die Einstellungsänderungen in *InnoMind* untersucht werden. Alternativ könnte der in dem Modell bislang realisierte Mechanismus der Beziehungsbildung durch das Prinzip der Einstellungshomophilie ersetzt werden und der Prozess Teil der dynamischen Elemente der Simulation werden.

9.2.3 Validierung

Die Validierung von agentenbasierten Modellen ist trotz einiger Fortschritte in den letzten Jahren weiterhin ein zentrales Thema der Forschung (Andreas Flache et al., 2017; Windrum, Fagiolo, & Moneta, 2007). Der Aspekt umfasst eine Vielzahl verschiedener miteinander verbundener Konzepte und Ansätze. Eine generelle Unterscheidung kann zwischen struktureller oder Input-Validierung und Output- oder empirischer Validierung vorgenommen werden (Manson, 2003; Richiardi, Leombruni, Saam, & Sonnessa, 2006). Ersteres bewertet, wie gut das Modell die Prozesse und Strukturen des realen Systems widerspiegelt, während Letzteres überprüft, wie gut die Ergebnisse der Simulationen die historischen Daten des realen Zielsystems repräsentieren.

In der vorliegenden Dissertation wurde der Schwerpunkt auf die Input-Validierung des Modells *InnoMind* gelegt. Hierzu wurde das ausgewählte Einstellungs- und Verhaltensmodell im Zuge der in Studie 1 durchgeführten experimentellen Untersuchung getestet und die Auswahl der Anfangsbedingungen sowie die Erkundung des Parameterraums wurden mithilfe einer Befragungsstudie und der Implementierung der empirischen Daten in das Modell (Studie 3) überprüft. Damit wurde eines der Hauptziele der Arbeit, nämlich die empirisch-experimentelle Grundlage sowie die psychologische Plausibilität von Simulationsmodellen sozialer Dynamiken zu verbessern, erreicht. Für die praktische Anwendung und Nützlichkeit des Ansatzes wäre jedoch eine umfassende Output-Validierung, also die Überprüfung, inwieweit die Ergebnisse der simulierten Szenarien mit den Einstellungen und Verhalten im Untersuchungskontext übereinstimmen und inwiefern das Modell gegebenenfalls auch in anderen Domänen valide Ergebnisse liefert, ein wichtiger nächster Schritt.

Die Umsetzung eines derartigen Vorhabens ist jedoch mit diversen Herausforderungen verbunden. Zwar existiert im Verkehrsbereich eine Vielzahl umfassender Zeitreihendatensätze zu Einstellungen und Mobilitätsverhalten (z. B. Mobilität in Deutschland (MiD), Deutsches Mobilitätspanel (MOP)), die theoretisch zur Output-Validierung und Erweiterung des Modells auf Gesamtdeutschland herangezogen werden könnten. Aufgrund unterschiedlicher Aspekte sind diese Daten jedoch nur eingeschränkt für diesen Zweck geeignet. Erstens ist man für die Mikrovalidierung von *InnoMind* auf intraindividuelle Einstellungsänderungen angewiesen. Die meisten langzeitlichen Panelstudien erheben jedoch vornehmlich Verhaltensdaten, sodass die den Einstellungsänderungen zugrunde liegenden Überzeugungen, Affekte und Prioritäten nur ungenau geschätzt werden könnten. Zweitens sind für Zeitreihenanalysen intraindividuelle Variationen erforderlich. Zeitliche Variationen von Einstellungen gegenüber der Nutzung von Verkehrsmitteln sind jedoch zumindest in kurz- und mittelfristigen Zeiträumen zeitlich relativ stabil. Drittens werden für die Mikrovalidierung des Modells Informationen über individuelle soziale Netzwerke benötigt, die in den Mobilitätsumfragen in der Regel nicht erhoben werden.

Vor dem Hintergrund erscheint es sinnvoll, die Output-Validierung des Modells wie auch den generellen Gültigkeitsanspruch des entwickelten Ansatzes im Kontext sozialer Dynamiken in einem anderen Themenkontext umzusetzen. Als besonders geeignet erscheint hier der Bereich der Einstellungs- und Meinungsforschung. Weltweit wird dazu eine Vielzahl von Längsschnittstudien in den verschiedensten Themengebieten durchgeführt, die eine umfassende, langzeitliche und sehr diverse Datengrundlage, häufig in dem für das Modell benötigten Detailgrad, darstellen. Im Rahmen der Analyse würde man den Grad der Ähnlichkeit zwischen den empirischen und den Simulationsdaten für zwei oder mehrere Zeitreihen auf Mikro- und Makroebene bewerten. Neuere Methoden wie das von Lamperti (2018) vorgeschlagene Informationskriterium, genannt *Generalized Subtracted L-divergence* (GSL-div), ermöglichen es, derartige zeitliche Verläufe auf der Basis ihrer Muster robust zu bewerten.

9.3 Implikationen und Perspektiven für Forschung und Praxis

Vor dem Hintergrund der bisherigen Ausführungen werden abschließend die Implikationen und Perspektiven für sozialwissenschaftliche Computersimulation, sogenannte soziale Simulationen, sowie die Forschung zu sozialen Einfluss- und Diffusionsprozessen aufgezeigt. Weiterhin wird der Versuch unternommen, die Bedeutung der Ergebnisse für die Praxis darzustellen.

In der Vergangenheit wurde wiederholt Kritik an der mangelnden psychologischen Plausibilität agentenbasierter Modelle geäußert (Sobkowicz, 2009; Sun, 2012). Die Ergebnisse dieser Arbeit leisten durch die Integration kognitionspsychologischer Theorien der Informationsverarbeitung an dieser Stelle einen wichtigen Beitrag zur Weiterentwicklung sozialer Simulationen. Zudem tragen die Resultate dazu bei die Effekte und sozialen Dynamiken, die sich durch die Wechselwirkung motivierter Informationsverarbeitung und sozialer Einflüsse ergeben, besser zu verstehen. Trotz diverser Fortschritte in dem Forschungsfeld liefern die bestehenden Verfahren jedoch immer noch keine hinreichend zuverlässigen Erklärungen und validen Vorhersagen, um öffentliche Debatten und die politische Entscheidungsfindung in wichtigen Transformationsfeldern zu informieren (vgl. Flache et al., 2017). Dass dies jedoch mit derartigen Methoden prinzipiell möglich ist, haben eine Vielzahl von Computersimulationsstudien im Zuge der aktuellen COVID-19 Pandemie eindrucksvoll veranschaulicht (vgl. Estrada, 2020). Zwei zentrale Merkmale bestimmen den praktischen Nutzen der Modelle: die strukturelle Validität der Modelle sowie deren empirische Datengrundlage. Zwei Aspekte zu deren Umsetzung in komplexeren Modellierungskontexten die vorliegende Dissertation Vorschläge unterbreitet.

Für die zukünftige Forschung im Bereich der Modellierung komplexer gesellschaftlicher Transformationsprozesse ergeben sich damit zwei zentrale Fragen: Erstens welche der vorgeschlagenen, teilweise umfassenden Einstellungs- und Verhaltenstheorien und Modelle, sind im direkten Vergleich besser geeignet, ein konkretes soziales Phänomen zu erklären und vorherzusagen? In diesem Zusammenhang sollten in zukünftigen Arbeiten die jeweiligen Annahmen der verschiedenen Modellierungsansätze gegenübergestellt und hinsichtlich ihrer Plausibilität und Validität geprüft werden. Zweitens gilt es in dem Kontext zu klären, unter welchen Bedingungen und Fragestellungen es sinnvoll und zielführend ist, den Detailgrad der (Sub-)Modelle zu erhöhen beziehungsweise zu reduzieren. Im Anwendungskontext der Verkehrswende stellt sich beispielsweise die Frage, ob die Aussagekraft und Validität eines Verkehrsnachfragemodells durch die explizite Abbildung intrapsychische Prozesse der Informationsverarbeitung verbessert werden kann. Verändern sich dadurch die Gesamtergebnisse der Simulation oder wird dadurch ein besseres Verständnis beispielsweise über bestimmte Kipppunkt des Systems erzielt? Im Sinne der Sparsamkeit, Effizienz und Kommunizierbarkeit von Simulationsergebnissen erscheint dieses

Vorgehen für transdisziplinäre und anwendungsorientierte Forschung auf den ersten Blick keinen bedeutsamen Mehrwert zu versprechen. Die Grundlagenforschung könnte jedoch dazu beitragen, für die auf kognitiv-affektiver Ebene stattfinden Prozesse, wie der in dieser Arbeit untersuchte Mechanismus emotionaler Kohärenz, vereinfachte Funktionen oder Parameter auf höheren Systemebenen zu entwickeln.

Darüber hinaus könnte der in dieser Dissertation vorgestellte Ansatz Eingang in die Forschung zu Prozessen sozialen Ansteckungen und Innovationsdiffusion finden (z. B. Centola, 2018, 2021; Valente, 2005). Der Fokus dieser häufig in der Soziologie angesiedelten Arbeiten liegt vornehmlich auf der Analyse sozialstruktureller Merkmale. Die Wechselwirkungen zwischen psychologischen und sozialen Prozessen im Zuge von Innovationsprozessen sind bislang nur unzureichend untersucht. Die gemeinsame Betrachtung der Einflussfaktoren der Innovationsadaption auf individueller und sozialer Ebene, wie dies in dem Modell *InnoMind* vorgenommen wird, stellt eine wichtige Erweiterung dar, um bestehender theoretischer Konzepte in diesem Forschungskontext zu einer umfassenderen formalisierten Theorie gesellschaftlicher Transformation weiterentwickeln zu können. Neuere experimentelle Methoden in dem Forschungsfeld der sozialen Netzwerkanalyse bieten dabei die Möglichkeit, theoretische Annahme zu prüfen und robuste empirische Grundlagen für anwendungsorientierte Modellansätze zu schaffen (z. B. Centola, 2011; Guilbeaulta et al., 2018).

Schließlich lassen aus den in dieser Arbeit vorgestellten Befunden Implikationen für die praktische Umsetzung der Verkehrswende ableiten. Während in den letzten Jahren zahlreiche technologische und soziale Innovationen als Lösungen für klimafreundlicheren Verkehr entstanden sind, zeigen die empirischen Ergebnisse, dass diese Alternativen von der Bevölkerung mehrheitlich noch nicht angenommen werden. Die größte Herausforderung ist in diesem Zusammenhang das Festhalten und die Dominanz der autozentrierten Mobilitätskultur in der Gesellschaft. Auf dem Weg zu einer neuen nachhaltigen Mobilitätkultur geht es neben der Schaffung entsprechender politischer Rahmenbedingungen und attraktiver Mobilitätsangebote auch um die Veränderung kulturell geprägt Verhaltens- und Deutungsmuster. Letztere werden einerseits durch instrumentelle Motive bei der Verkehrsmittelwahl bestimmt und andererseits durch emotionale Bedürfnisse, Werte sowie soziale Einflüsse und Normen beeinflusst. Ordnungsrechtliche Rahmensetzung und finanzielle Anreize zur Veränderung von Mobilitätseinstellungen und -verhalten greifen daher zu kurz. Zusätzlich wird des nötig sein, neue verkehrspolitische Leitbilder und Narrative nachhaltiger Mobilität auf Basis bestehender Einstellungen, Werte und Bedürfnisse und unter Beteiligung unterschiedlicher gesellschaftlicher Gruppen zu entwickeln.

Literaturverzeichnis

Abelson, R. P. (1964). Mathematical models of the distribution of attitudes under controversy. In N. Frederiksen & H. Gulliksen (Eds.), *Contributions to Mathematical Psychology* (pp. 142–160). New York, NY: Holt, Rinehart and Winston.

Abelson, R. P., & Rosenberg, M. J. (1958). Symbolic psychologic: A model of attitudinal cognition. *Behavioral Science*, *3*(1), 1–13.

Agora Verkehrswende. (2020). Baustellen der Mobilitätswende. Wie sich die Menschen in Deutschland fortbewegen und was das für die Verkehrspolitik bedeutet.

Akers, R. L., Krohn, M. D., Lanza-Kaduce, L., & Radosevich, M. (1979). Social Learning and Deviant Behavior: A specific Test of a general Theory. *American Sociological Review*, *44*, 636–655.

Alan, A. R. (2006). *Social marketing in the 21st century*. Thousand Oaks, CA: SAGE Publications Inc. https://doi.org/10.4135/9781483329192

Albarracin, D., & Shavitt, S. (2018). Attitudes and Attitude Change. *Annual Review of Psychology*, *69*, 299–327. https://doi.org/10.1146/annurev.psych.121208.131609

Allport, F. H. (1924). *Social psychology*. Boston: Houghton Mifflin.

Amblard, F. (2002). Which ties to choose? A survey of social networks models for agent-based social simulations. In *SCS International Conference On Artificial Intelligence, Simulation and Planning in High Autonomy Systems* (pp. 253–258).

Amblard, Frédéric, & Deffuant, G. (2004). The role of network topology on extremism propagation with the relative agreement opinion dynamics. *Physica A: Statistical Mechanics and Its Applications*, *343*(1–4), 725–738. https://doi.org/10.1016/j.physa.2004.06.102

Ambrasat, J. (2017). Affektive Wahrnehmung von politischen Parteien. *Kölner Zeitschrift Für Soziologie Und Sozialpsychologie*, *69*(2), 307–330. https://doi.org/10.1007/s11577-017-0435-4

Ambrasat, J., von Scheve, C., Conrad, M., Schauenburg, G., & Schröder, T. (2014). Consensus and stratification in the affective meaning of human sociality. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(22), 8001–8006. https://doi.org/10.1073/pnas.1313321111

Anable, J., Kinnear, N., Hutchins, R., & Skippon, S. (2016). *Consumer segmentation and demographic patterns*. Transport Research Laboratory Report. Retrieved from https://trl.co.uk/reports/PPR769?reportid=7035

Anable, Jillian. (2005). 'Complacent Car Addicts' or 'Aspiring Environmentalists'? Identifying travel behaviour segments using attitude theory. *Transport Policy*, *12*(1), 65–78.

Anable, Jillian, & Gatersleben, B. (2005). All work and no play? The role of instrumental and affective factors in work and leisure journeys by different travel modes. *Transportation Research Part A: Policy and Practice*, *39*(2–3), 163–181. https://doi.org/10.1016/j.tra.2004.09.008

Asch, S. E. (1946). Forming impressions of personality. *The Journal of Abnormal and Social Psychology*, *41*(3), 258–290. https://doi.org/10.1037/h0055756

Asch, S. E. (1952). *Social psychology*. New York: Prentice Hall.

Axelrod, R. (1997). The dissemination of culture - A model with local convergence and global polarizatio. *Journal of Conflict Resolution*, *41*(2), 203–226.

Axsen, J., & Kurani, K. S. (2011). Interpersonal influence in the early plug-in hybrid market: Observing social interactions with an exploratory multi-method approach. *Transportation*

Research Part D: Transport and Environment, *16*(2), 150–159. https://doi.org/10.1016/j.trd.2010.10.006

Balmer, M., Rieser, M., Meister, K., Charypar, D., Lefebvre, N., & Nagel, K. (2009). MATSim-T: Architecture and simulation. In A. L. C. Bazzan & F. Klugl (Eds.), *Multi-agent systems for traffic and transportation engineering* (pp. 57–78). Hershey, PA: GI Global.

Banaji, M. R., & Heiphetz, L. (2010). Attitudes. In S. T. Fiske, D. T. Gilbert, & G. Lindzey (Eds.), *Handbook of Social Psychology* (pp. 353–393). Hoboken: Wiley.

Bayes, R., Druckman, J. N., Goods, A., & Molden, D. C. (2020). When and How Different Motives Can Drive Motivated Political Reasoning. *Political Psychology*, *41*(5), 1031–1052. https://doi.org/10.1111/pops.12663

Beck, M., & Opp, K. D. (2001). Der faktorielle Survey und die Messung von Normen. *Kölner Zeitschrift Für Soziologie Und Sozialpsychologie*, *53*(2), 283–306.

Beierlein, C., Kovaleva, A., Kemper, C. J., & Rammstedt, B. (2015). Kurzskala zur Erfassung der Risikobereitschaft (R-1). https://doi.org/10.6102/zis236

Beierlein, C., Kovaleva, A., László, Z., Kemper, C. J., & Rammstedt, B. (2015). Kurzskala zur Erfassung der Allgemeinen Lebenszufriedenheit (L-1). https://doi.org/10.6102/zis229

Betsch, T., & Glöckner, A. (2010). Intuition in judgment and decision making: Extensive thinking without effort. *Psychological Inquiry*, *21*(4), 279–294. https://doi.org/10.1080/1047840X.2010.517737

Bland, A. (2013). Tories identify eight groups of voters as Labour look to Obama campaign for inspiration: the sophisticated tools that rivals hope will win them 2015 election revealed. *The Independent*. Retrieved from http://www.independent.co.uk/news/uk/politics/tories-identify-eight-groups-of-voters-as-labour-look-to- obama-campaign-for-inspiration-the-sophisticated- tools-that-rivals-hope-will-win-them-2015-election- revealed-8925374.html

BMUB. (2017). *Klimaschutz in Zahlen. Fakten, Trends und Impulse deutscher Klimapolitik*. Retrieved from http://www.bmub.bund.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutz_in_zahlen_2017_bf.pdf

BMVBS. (2012). *Chancen des ÖPNV in Zeiten einer Renaissance der Städte. BMVBS-Online-Publikation*. Retrieved from http://www.bbsr.bund.de/nn_629248/BBSR/DE/Veroeffentlichungen/BMVBS/Online/2012/ON012012.html

Boer, D. (2013). SSVS-G. Deutsche Kurzskala des Wertefragebogens von S.H. Schwartz (Short Schwartz‘s Value Survey). In C. Kemper, M. Zenger, & E. Brähler (Eds.), *Psychologische und sozialwissenschaftliche Kurzskalen - Standardisierte Erhebungsinstrumente für Wissenschaft und Praxis*. Berlin: Medizinisch- Wissenschaftlichen Verlagsgesellschaft.

Bohner, G., & Dickel, N. (2011). Attitudes and attitude change. *Annual Review of Psychology*, *62*, 391–417. https://doi.org/10.1146/annurev.psych.121208.131609

Bolsen, T., Druckman, J. N., & Cook, F. L. (2014). The Influence of Partisan Motivated Reasoning on Public Opinion. *Political Behavior*, *36*(2), 235–262. https://doi.org/10.1007/s11109-013-9238-0

Bösehans, G., & Walker, I. (2018). Do supra-modal traveller types exist ? A travel behaviour market segmentation using Goal framing theory. *Transportation*, (Anable 2005). https://doi.org/10.1007/s11116-018-9874-7

Brien, B. K. O. (2015). Political agency: The key to tackling climate change. *Science (New York, N.Y.)*, *350*(6265).

Brownstein, A. L. (2003). Biased predecision processing. *Psychological Bulletin*. Brownstein, Aaron L.: Department of Psychology, University of Southern California, SGM 501, Los Angeles, CA, US, 90089-1061, aaronb@usc.edu: American Psychological Association. https://doi.org/10.1037/0033-2909.129.4.545

Burt, R. S. (1991). Age as a Structural Concept. *Social Networks*, *19*, 355–373.

Byrne, D., Core, G. L., & Smeaton, G. (1986). The Attraction Hypothesis: Do Similar Attitudes Affect Anything? *Journal of Personality and Social Psychology*, *51*, 1167–1170.

Cacioppo, J. T., Petty, R. E., & Green, T. R. (1989). From the tripartite model to the homeostasis model of attitudes. In A. R. Pratkanis, S. J. Breckler, & A. G. Greenwald (Eds.), *Attitude structure and function* (pp. 275–310). Hillsdale, NJ: Lawrence Erlbaum.

Castellano, C., Fortunato, S., & Loreto, V. (2009). Statistical physics of social dynamics. *Reviews of Modern Physics*, *81*(2), 591–646. https://doi.org/10.1103/RevModPhys.81.591

Centola, D. (2011). An experimental study of homophily in the adoption of health behavior. *Science (New York, N.Y.)*, *334*(6060), 1269–1272. https://doi.org/10.1126/science.1207055

Centola, D. (2018). *How Behavior Spreads: The Science of Complex Contagions*. Princeton, New Jersey: Princeton University Press.

Centola, D. (2021). *Change: How to Make Big Things Happen*. New York: Little, Brown & Co.

Chaiken, S., & Trope, Y. (1999). *Dual-Process Theories in Social Psychology*. Retrieved from http://books.google.com/books?hl=de&lr=&id=5X_auIBx99EC&pgis=1

Chen, F. F., & Kenrick, D. T. (2002). Repulsion or Attraction? Group Membership and Assumed Attitude Similarity. *Journal of Personality and Social Psychology*, *83*, 111–125.

Chong, D., & Druckman, J. N. (2007). Framing theory. *Annual Review of Political Science*, *10*, 103–126. https://doi.org/10.1146/annurev.polisci.10.072805.103054

Cialdini, R. B., & Trost, M. R. (1998). Social influence: Social norms, conformity and compliance. In D. T. Gilbert, S. T. Fiske, & G. Lindzey (Eds.), *The handbook of social psychology* (4. Auflage, pp. 151–192). New York: McGraw-Hill.

Clark, B., Chatterjee, K., Melia, S., Knies, G., & Laurie, H. (2014). Life Events and Travel Behavior: Exploring the Interrelationship Using UK Household Longitudinal Study Data. *Transportation Research Record*, *2413*(1), 54–64. https://doi.org/10.3141/2413-06

Conte, R., & Giardini, F. (2016). Towards computational and behavioral social science. *European Psychologist*, *21*(2), 131–140. https://doi.org/10.1027/1016-9040/a000257

Corner, A., & Randall, A. (2011). Selling climate change? The limitations of social marketing as a strategy for climate change public engagement. *Global Environmental Change*, *21*(3), 1005–1014. https://doi.org/10.1016/j.gloenvcha.2011.05.002

Creutzig, F., Jochem, P., Edelenbosch, O. Y., Mattauch, L., van Vuuren, D. P., McCollum, D., & Minx, J. (2015). Energy and environment. Transport: A roadblock to climate change mitigation? *Science (New York, N.Y.)*, *350*(6263), 911–912. https://doi.org/10.1126/science.aac8033

Dalege, J., Borsboom, D., van Harreveld, F., van den Berg, H., Conner, M., & van der Maas, H. L. J. (2015). Toward a formalized account of attitudes: The causal attitude network (CAN) model. *Psychological Review*, *123*(1), 2–22. https://doi.org/10.1037/a0039802

de Haan, G., Lantermann, E.-D., Linneweber, V., & Reusswig, F. (2001). *Typenbildung in der sozialwissenschaftlichen Umweltforschung*. (G. De Haan, E.-D. Lantermann, V. Linneweber, & F. Reusswig, Eds.). Opladen: Leske + Budrich.

Deffuant, G., Neau, D., Amblard, F., & Weisbuch, G. (2000). Mixing beliefs among interacting agents. *Advances in Complex Systems*, *3*, 87–98. https://doi.org/10.1142/S0219525900000078

Degroot, M. H. (1974). Reaching a Consensus. *Journal of the American Statistical Association*, *69*, 118–121.

DeKay, M. L., Miller, S. A., Schley, D. R., & Erford, B. M. (2014). Proleader and antitrailer information distortion and their effects on choice and postchoice memory. *Organizational Behavior and Human Decision Processes*, *125*(2), 134–150. https://doi.org/10.1016/J.OBHDP.2014.07.003

DellaPosta, D., Shi, Y., & Macy, M. (2015). Why Do Liberals Drink Lattes? *American Journal of Sociology*, *120*(5), 1473–1511. https://doi.org/10.1086/681254

Deutsch, M., & Gerard, H. B. (1955). A study of normative and informational social influences upon individual judgment. *The Journal of Abnormal and Social Psychology*, *51*(3), 629–636.

Dibb. (1999). Criteria guiding segmentation implementation: reviewing the evidence. *Journal of Strategic Marketing*, *7*, 107–129.

Estrada, E. (2020). COVID-19 and SARS-CoV-2. Modeling the present, looking at the future. *Physics Reports*, *869*, 1–51. https://doi.org/10.1016/j.physrep.2020.07.005

Fazio, R. H., & Olson, M. A. (2003). Attitudes: Foundations, functions, and consequences. In H. & J. Cooper (Ed.), *The handbook of social psychology* (pp. 139–160). London, UK: Sage.

Feldman, L., & Hart, P. S. (2018). Climate change as a polarizing cue: Framing effects on public support for low-carbon energy policies. *Global Environmental Change*, *51*(May), 54–66. https://doi.org/10.1016/j.gloenvcha.2018.05.004

Feliciani, T., Flache, A., & Tolsma, J. (2017). How, when and where can spatial segregation induce opinion polarization? Two competing models. *Journal of Artificial Societies and Social Simulation*, *20*(2). https://doi.org/10.18564/jasss.3419

Festinger, L. (1957). *The theory of cognitive dissonance*. California: Stanford University Press.

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behavior: An introduction to theory and research*. Reading, MA: Addison-Wesley.

Flache, A., & Mäs, M. (2008). How to get the timing right? A computational model of how demographic faultlines undermine team performance and how the right timing of contacts can solve the problem. *Computational and Mathematical Organization Theory*, *14*, 23–51.

Flache, Andreas, Mäs, M., Feliciani, T., Chattoe-Brown, E., Deffuant, G., Huet, S., & Lorenz, J. (2017). Models of Social Influence: Towards the Next Frontiers. *Journal of Artificial Societies and Social Simulation*, *20*(4), 2. https://doi.org/10.18564/jasss.3521

Fontaine, J. R. J., Scherer, K. R., Roesch, E. B., & Ellsworth, P. C. (2007). The World of Emotions is not Two-Dimensional. *Psychological Science*, *18*(12), 1050–1057. https://doi.org/10.1111/j.1467-9280.2007.02024.x

Galam, S. (2004). Contrarian deterministic effects on opinion dynamics: the hung elections scenario. *Physica A*, *333*, 453–460.

Gigerenzer, G. (2004). Fast and frugal heuristics: The tools of bounded rationality. In D. Koehler & N. Harvey (Eds.), *Handbook of judgment and decision making* (pp. 62–88). Oxford, UK: Blackwell.

Gigerenzer, G., Todd, P. M., & Group, A. R. (1999). *Simple heuristics that make us smart*. New York, NY: Oxford University Press.

Gigerenzer, G, & Goldstein, D. G. (1996). Reasoning the fast and frugal way: models of bounded rationality. *Psychological Review*, *103*(4), 650–669.

Gigerenzer, Gerd, & Gaissmaier, W. (2011). Heuristic Decision Making. *Annual Review of Psychology*, *62*, 451–482. https://doi.org/10.1146/annurev-psych-120709-145346

Gilbert, N. (2010). *Computational Social Science.* (N. Gilbert, Ed.). Thousand Oaks, CA: SAGE Publications Ltd.

Gilbert, N., & Troitzsch, K. (2005). *Simulation for the Social Scientist*. Buckingham: Open University Press.

Gilbert, N., & Troitzsch, K. G. (1999). *Simulation for the Social Scientist* (2nd ed.). Open University Press.

Glöckner, A., & Betsch, T. (2008). Modeling option and strategy choices with connectionist networks : Towards an integrative model of automatic and deliberate decision making. *Judgment and Decision Making*, *3*(3), 215–228.

Glöckner, A., & Witteman, C. (2010). Beyond dual-process models : A categorisation of processes underlying intuitive judgement and decision making. *Thinking and Reasoning*, *16*(1), 1–25.

Gloeckner, A., Betsch, T., & Schindler, N. (2010). Coherence Shifts in Probabilistic Inference Tasks. *Journal of Behavioral Decision Making*, *23*, 439–462. https://doi.org/10.1002/bdm.668

Gnambs, T., & Batinic, B. (2011). Evaluation of measurement precision with Rasch-type models: The case of the short Generalized Opinion Leadership Scale. *Personality and Individual Differences*, *50*(1), 53–58. https://doi.org/10.1016/j.paid.2010.08.021

Guilbeault, D., Becker, J., & Centola, D. (2018). Complex Contagions: A Decade in Review. In S. Lehmann & Y. Ahn (Eds.), *Spreading Dynamics in Social Systems* (pp. 3–25). New York: Springer.

Guilbeaulta, D., Beckera, J., & Centola, D. (2018). Social learning and partisan bias in the interpretation of climate trends. *Proceeding of the National Academy of Scienes*, *115*(39), 9714–9719. https://doi.org/10.1073/pnas.1722664115

Hamill, L., & Gilbert, N. (2009). Social Circles: A Simple Structure for Agent-Based Social Network Models. *Journal of Artificial Societies and Social Simulation*, *12*(2).

Harless, D. W., & Camerer, C. F. (1994). The Predictive Utility of Generalized Expected Utility Theories. *Econometrica*, *62*(6), 1251–1289. Retrieved from url: https://www.jstor.org/stable/2951749

Harmon-Jones, E., & Mills, J. (1999). *Cognitive dissonance: Progress on a pivotal theory in social psychology.* (Eddie Harmon-Jones & J. Mills, Eds.). Washington, DC, US: American Psychological Association. https://doi.org/https://doi.org/10.1037/10318-000

Hart, P. S., & Nisbet, E. C. (2012). Boomerang Effects in Science Communication: How Motivated Reasoning and Identity Cues Amplify Opinion Polarization About Climate Mitigation Policies. *Communication Research*, *39*(6), 701–723. https://doi.org/10.1177/0093650211416646

Hegselmann, R., & Krause, U. (2002). Opinion Dynamics and Bounded Confidence Models: Analysis and Simulation. *Journal OfArtificial Societies and Social Simulation*, *5*(3).

Heider, F. (1946). Attitudes and cognitive organization. *The Journal of Psychology*, *21*(1), 107–112.

Heider, F. (1958). *The Psychology of Interpersonal Relations*. New York: Wiley.

Heise, D. R. (2007). *Expressive order: Confirming sentiments in social action*. New York: Springer.

Heise, D. R. (2010). *Surveying Cultures: Discovering Shared Conceptions and Sentiments* -. New York:

John Wiley & Sons.

Hildebrand, E. D. (2003). Dimensions in elderly travel behaviour: A simplified activity-based model using lifestyle clusters. *Transportation*, *30*, 285–306.

Hine, D. W., Reser, J. P., Morrison, M., Phillips, W. J., Nunn, P., & Cooksey, R. (2014). Audience segmentation and climate change communication: Conceptual and methodological considerations. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(4), 441–459. https://doi.org/10.1002/wcc.279

Holyoak, K. J., & Powell, D. (2016). Deontological coherence: A framework for commonsense moral reasoning. *Psychological Bulletin*, *142*(11), 1179–1203. https://doi.org/10.1037/bul0000075

Holyoak, K. J., & Thagard, P. (1989). Analogical mapping by constraint satisfaction. *Cognitive Science*, *13*, 295–355.

Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceeding of the National Academy of Scienes*, *79*, 2554–2558. https://doi.org/10.1201/9780429500459

Hunecke, M., Haustein, S., Bohler, S., & Grischkat, S. (2010). Attitude-Based Target Groups to Reduce the Ecological Impact of Daily Mobility Behavior. *Environment and Behavior*, *42*(1), 3–43. https://doi.org/10.1177/0013916508319587

Hunecke, Marcel. (2015). *Mobilitätsverhalten verstehen und verändern: Psychologische Beiträge zur interdisziplinären Mobilitätsforschun*. Wiesbaden: Springer VS.

Jager, W., & Amblard, F. (2005). Uniformity, bipolarization and pluriformity captured as generic stylized behavior with an agent-based simulation model of attitude change. *Computational & Mathematical Organization Theory*, *10*(4), 295–303.

Jasso, G. (2006). Factorial Survey Methods for Studying Beliefs and Judgments. Sociological Methods Research 34: S. 334-423. *Sociological Methods Research*, *34*, 334–423.

Johnson, E. J., Häubl, G., & Keinan, A. (2007). Aspects of endowment: A query theory of value construction. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. Johnson, Eric J.: Columbia Business School, Columbia University, 514 Uris Hall, New York, NY, US, 10027, ejj3@columbia.edu: American Psychological Association. https://doi.org/10.1037/0278-7393.33.3.461

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, *2*(10), 732–735. https://doi.org/10.1038/nclimate1547

Kahneman, D. (2003). A perspective on judgment and choice: Mapping bounded rationality. *American Psychologist*. Kahneman, Daniel: Department of Psychology, Princeton University, Princeton, NJ, US, 08544-1010, kahneman@princeton.edu: American Psychological Association. https://doi.org/10.1037/0003-066X.58.9.697

Kahneman, D., & Tversky, A. (1979). Prospect Theory : An Analysis of Decision under Risk. *Econometrica*, *47*(2), 263–292. Retrieved from http://www.jstor.org/stable/1914185%5Cnhttp://www.jstor.org/%5Cnhttp://www.jstor.org/action/showPublisher?publisherCode=econosoc.%5Cnhttp://www.jstor.org

Kahnemann, D. (2011). *Thinking, fast and slow*. New York: Penguin.

Kandt, J., Rode, P., Hoffmann, C., Graff, A., & Smith, D. (2015). Gauging interventions for sustainable travel: A comparative study of travel attitudes in Berlin and London. *Transportation Research Part A: Policy and Practice*, *80*, 35–48. https://doi.org/10.1016/j.tra.2015.07.008

Keren, G. (2010). *Perspectives on Framing*. New York: Psychology Press. https://doi.org/https://doi.org/10.4324/9780203854167

Kiesling, E., Günther, M., Stummer, C., & Wakolbinger, L. M. (2011). Agent-based simulation of innovation diffusion: a review. *Central European Journal of Operations Research*, *20*(2), 183–230.

Kotler, P., & Zaltman, G. (1971). Social marketing: an approach to planned social change. J Mark. *Journal of Marketing*, *35*, 3–12.

Krajbich, I., Lu, D., Camerer, C., & Rangel, A. (2012). The attentional drift-diffusion model extends to simple purchasing decisions. *Frontiers in Psychology*, *3*(193). https://doi.org/https://doi.org/10.3389/fpsyg.2012.00193

Kuhnimhof, T., Nobis, C., Hillmann, K., Follmer, R., & Eggs, J. (2019). *Veränderungen im Mobilitätsverhalten zur Förderung einer nachhaltigen Mobilität*. Dessau-Roßlau.

Kunda, Z., & Thagard, P. (1996). Forming Impressions from Stereotypes, Traits, and Behaviors A prarallel-constraint satisfaction theory. *Psychological Review*, *103*(2), 284–308.

Lamperti, F. (2018). An information theoretic criterion for empirical validation of simulation models. *Econometrics and Statistics*, *5*, 83–106. https://doi.org/https://doi.org/10.1016/j.ecosta.2017.01.006

Lee, J., & Holyoak, K. J. (2020). "But he's my brother": The impact of family obligation on moral judgments and decisions. *Memory and Cognition*, *48*(1), 158–170. https://doi.org/10.3758/s13421-019-00969-7

Lehrer, K. (1975). Social consensus and rational agnoiology. *Synthese*, *31*, 141–160.

Lerner, J. S., Li, Y., Valdesolo, P., & Kassam, K. S. (2015). Emotion and decision making. *Annual Review of Psychology*, *45*(1–3), 133–155. https://doi.org/10.1016/0001-6918(80)90026-8

Levin, I. P., Schneider, S. L., & Gaeth, G. J. (1998). All Frames Are Not Created Equal: A Typology and Critical Analysis of Framing Effects, Organizational Behavior and Human Decision Processes. *Organizational Behavior and Human Decision Processes*, *76*(2), 149–188. https://doi.org/https://doi.org/10.1006/obhd.1998.2804

Li, Z., Yang, C., Wang, W., & Ragland, D. (2013). Bicycle commuting market segmentation analysis using attitudinal factors. *Transportation Research Part A: Policy and Practice*, *47*, 56–68.

Liu, C. C., & Srivastava, S. B. (2015). Pulling Closer and Moving Apart: Interaction, Identity, and Influence in the U.S. Senate, 1973 to 2009. *American Sociological Review*, *80*(1), 192–217. https://doi.org/10.1177/0003122414564182

Loewenstein, G. F., & Lerner, J. S. (2003). The role of affectt in decision making. In R. Davidson, K. Scherer, & H. Goldsmith (Eds.), *Handbook of affectivce science* (pp. 619–642). New York: Oxford University Press.

Lorenz, J. (2007). Continuous opinion dynamics under bounded confidence: A survey. *International Journal of Modern Physics C*, *18*(12), 1819–1838. https://doi.org/10.1142/S0129183107011789

MacKinnon, N. J. (1994). *Symbolic interactionism as affect control*. Albany, NY: State University of New York Press.

MacKinnon, Neil J., & Heise, D. R. (2010). *Self, Identity, and Social Institutions*. New York: NY: Palgrave Macmillan.

Macy, M. W., Kitts, J. A., Flache, A., & Benard, S. (2003). A Hopfield Model of Emergent Structure. In R. Breiger, K. M. Carley, & P. Pattison (Eds.), *Dynamic Social Network Modeling and Analysis: Workshop Summary and Papers*. Washington, DC: National Academies Press.

Macy, Michael W., & Willer, R. (2002). From Factors to Factors: Computational Sociology and Agent-Based Modeling. *Annual Review of Sociology*, *28*(1), 143–166. https://doi.org/10.1146/annurev.soc.28.110601.141117

Maibach, E. W., Leiserowitz, A., Roser-Renouf, C., & Mertz, C. K. (2011). Identifying like-minded audiences for global warming public engagement campaigns: An audience segmentation analysis and tool development. *PLoS ONE*, *6*(3). https://doi.org/10.1371/journal.pone.0017571

Manson, S. M. (2003). Validation and verification of multi-agent models for ecosystem management. In M. Janssen (Ed.), *Complexity and Ecosystem Management: The Theory and Practice of Multi-Agent Approaches* (pp. 63–74). Northampton, Massachusetts: Edward Elgar Publishers.

Marsden, P. V. (1988). Homogeneity in confiding relations. *Social Networks*, *10*, 57–76.

Mäs, M., Flache, A., & Helbing, D. (2010). Individualization as driving force of clustering phenomena in humans. *PLoS Computational Biology*, *6*(10). https://doi.org/10.1371/journal.pcbi.1000959

Mathijssen, J., Janssen, M., van Bon-Martens, M., & van de Goor, I. (2012). Adolescents and alcohol: an explorative audience segmentation analysis. *BMC Public Health*, *12*(1), 742. https://doi.org/10.1186/1471-2458-12-742

Mattauch, L., Ridgway, M., & Creutzig, F. (2015). Happy or liberal? Making sense of behavior in transport policy design. *Transportation Research Part D: Transport and Environment*, *45*, 64–83. https://doi.org/10.1016/j.trd.2015.08.006

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part I. An account of basic findings. *Psychological Review*, *88*, 365–405.

McClelland, J. L., & Rumelhart, D. E. (1986). *Parallel distributed processing: Explorations in the microstructure of cognition: Vol. 2 Psychological and biological models*. Cambridge, MA: MIT Press.

McCollum, D. L., Wilson, C., Bevione, M., Carrara, S., Edelenbosch, O. Y., Emmerling, J., … van Vuuren, D. P. (2018). Interaction of consumer preferences and climate policies in the global transition to low-carbon vehicles. *Nature Energy*, *3*(8), 664–673. https://doi.org/10.1038/s41560-018-0195-z

McCollum, D. L., Wilson, C., Pettifor, H., Ramea, K., Krey, V., Riahi, K., … Fujisawa, S. (2016). Improving the behavioral realism of global integrated assessment models: An application to consumers' vehicle choices. *Transportation Research Part D: Transport and Environment*, 1–10. https://doi.org/10.1016/j.trd.2016.04.003

McPherson, M. (2004). A Blau space primer: prolegomenon to an ecology of affiliation. *Industrial and Corporate Change*, *13*(1), 263–280. https://doi.org/10.1093/icc/13.1.263

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in Social Networks. *Annual Review of Sociology*, *27*, 415–444.

McPherson, Miller, J., & Smith-Lovin, L. (1987). Homophily in Voluntary Organizations: Status Distance and the Composition of Face-to-Face Groups. *American Sociological Review*, *52*, 370–379.

Mercure, J.-F., Pollitt, H., Bassi, A. M., Viñuales, J. E., & Edwards, N. R. (2016). Modelling complex systems of heterogeneous agents to better design sustainability transitions policy. *Global Environmental Change*, *37*, 102–115. https://doi.org/10.1016/J.GLOENVCHA.2016.02.003

Metcalfe, R., & Dolan, P. (2012). Behavioural economics and its implications for transport. *Journal of Transport Geography*, *24*, 503–511. https://doi.org/10.1016/j.jtrangeo.2012.01.019

Metzger, W. (1966). Figural-Wahrnehmung. In W. Metzger (Ed.), *Handbuch der Psychologie. 1. Band: Der Aufbau des Erkennens* (pp. 693–744). Göttingen: Hogrefe.

Monroe, B. M., & Read, S. J. (2008). A general connectionist model of attitude structure and change: the ACS (Attitudes as Constraint Satisfaction) model. *Psychological Review*, *115*(3), 733–759.

Montanari, A., & Saberi, A. (2010). The spread of innovations in social networks. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(47), 20196–20201. https://doi.org/10.1073/pnas.1004098107

Moons, I., & De Pelsmacker, P. (2015). An Extended Decomposed Theory of Planned Behaviour to Predict the Usage Intention of the Electric Car: A Multi-Group Comparison. *Sustainability*, *7*(5), 6212–6245. https://doi.org/10.3390/su7056212

Morton, C., Anable, J., & Nelson, J. D. (2017). Consumer structure in the emerging market for electric vehicles: Identifying market segments using cluster analysis. *International Journal of Sustainable Transportation*, *11*(6), 443–459. https://doi.org/10.1080/15568318.2016.1266533

Moss, R. H., Edmonds, J. a, Hibbard, K. a, Manning, M. R., Rose, S. K., van Vuuren, D. P., … Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, *463*(7282), 747–756. https://doi.org/10.1038/nature08823

Moussaïd, M. (2013). Opinion Formation and the Collective Dynamics of Risk Perception. *PloS One*, *8*(12), e84592. https://doi.org/10.1371/journal.pone.0084592

Mullainathan, S., & Thaler, R. (2000). *Behavioral economics* (No. 00–27).

Myers. (1982). Polarizing effects of social interaction. In H. Brandstatter, J. H. Davis, & G. Stocker-Kreichgauer (Eds.), *Group Decision Making*. London, UK.: Academic Press.

Nadini, M., Sun, K., Ubaldi, E., Starnini, M., Rizzo, A., & Perra, N. (2018). Epidemic spreading in modular time-varying networks. *Scientific Reports*, *8*(1), 1–11. https://doi.org/10.1038/s41598-018-20908-x

Nationale Plattform Elektromobilität. (2011). *Zweiter Bericht der Nationalen Plattform Elektromobilität Zweiter Bericht der Nationalen Plattform Elektromobilität*. Berlin. Retrieved from https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/zweiter-bericht-der-nationalen-plattform-fuer-elektromobilitaet.pdf?__blob=publicationFile&v=3

Negahban, A., & Yilmaz, L. (2014). Agent-based simulation applications in marketing research: an integrated review. *Journal of Simulation*, *8*(2), 129–142. https://doi.org/10.1057/jos.2013.21

Nerb, J. (2007). Exploring the dynamics of the appraisal – emotion relationship : A constraint satisfaction model of the appraisal process. *Cognition and Emotion*, *21*, 382–1413.

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology*, *2*(2), 175–220.

Nobis, C. (2020). *Baustellen der Mobilitätswende. Wie sich die Menschen in Deutschland fortbewegen und was das für die Verkehrspolitik bedeutet*. Berlin.

Oppenheimer, D. M., & Kelso, E. (2015). Information Processing as a Paradigm for Decision Making. *Annual Review of Psychology*, *66*(1), 277–294. https://doi.org/10.1146/annurev-psych-010814-015148

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The Measurement of Meaning*. Urbana: University of Illinois Press.

Osgood, C. E., & Tannenbaum, P. H. (1955). The principle of congruity in the prediction of attitude change. *Psychological Review*, *62*(1), 42–55.

Payne, J. W., Bettman, J. R., & Johnson, E. J. (1988). Adaptive strategy selection in decision making. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(3), 534–552. https://doi.org/10.1037/0278-7393.14.3.534

Pettifor, H., Wilson, C., Axsen, J., Abrahamse, W., & Anable, J. (2017). Social influence in the global diffusion of alternative fuel vehicles – A meta-analysis. *Journal of Transport Geography*, *62*(July), 247–261. https://doi.org/10.1016/j.jtrangeo.2017.06.009

Petty, R. E., & Briñol, P. (2015). Emotion and persuasion: Cognitive and meta-cognitive processes impact attitudes. *Cognition and Emotion*, *29*(April 2015), 1–26. https://doi.org/10.1080/02699931.2014.967183

Pfister, H.-R., Jungermann, H., & Fischer, K. (2017). *Die Psychologie der Entscheidung - Eine Einführung*. Berlin, Heidelberg: Springer. https://doi.org/https://doi.org/10.1007/978-3-662-53038-2

Poortinga, W., & Darnton, A. (2016). Segmenting for Sustainability: The Development of a Welsh Model to Engage the Public in Sustainability and Sustainability-Related Issues. *Journal of Environmental Psychology*, *45*, 221–232. https://doi.org/10.1016/j.jenvp.2016.01.009

Prillwitz, J., & Barr, S. (2011). Moving towards sustainability? Mobility styles, attitudes and individual travel behaviour. *Journal of Transport Geography*, *19*(6), 1590–1600. https://doi.org/10.1016/j.jtrangeo.2011.06.011

Pronello, C., & Camusso, C. (2011). Travellers' profiles definition using statistical multivariate analysis of attitudinal variables. *Journal of Transport Geography*, *19*(6), 1294–1308. https://doi.org/10.1016/j.jtrangeo.2011.06.009

Rai, V., & Henry, A. D. (2016). Agent-based modelling of consumer energy choices. *Nature Climate Change*, (May). https://doi.org/10.1038/nclimate2967

Raux, C., Chevalier, A., Bougna, E., & Hilton, D. (2020). Mobility choices and climate change: Assessing the effects of social norms, emissions information and economic incentives. *Research in Transportation Economics*, 101007. https://doi.org/https://doi.org/10.1016/j.retrec.2020.101007

Read, S. J., & Miller, L. C. (1998). On the dynamic construction of meaning: An interactive activation and competition model of social perception. In S. J. Read & L. C. Millder (Eds.), *Connectionist models of social reasoning and social behavior*. Mahwah, NJ: Lawrence Elrbaum Associates.

Read, S J, Vanman, E. J., & Miller, L. C. (1997). Connectionism, parallel constraint satisfaction processes, and gestalt principles: (re) introducing cognitive dynamics to social psychology. *Personality and Social Psychology Review*, *1*(1), 26–53. https://doi.org/10.1207/s15327957pspr0101_3

Read, Stephen J, & Monroe, B. M. (1994). Dissonance and balance in belief systems: The promise of parallel constraint satisfaction processes and connectionist modeling approaches. In R. C. Schank & E. J. Langer (Eds.), *Beliefs, reasoning, and decision making: Psycho-logic in honor of Bob Abelson* (pp. 209–235). Hillsdale, NJ: Erlbaum.

Read, Stephen J, & Simon, D. (2012). Parallel constraint satisfaction as a mechanism for cognitive consistency. In *Cognitive consistency: A fundamental principle in social cognition.* (pp. 66–86). New York, NY, US: Guilford Press.

Richiardi, M., Leombruni, R., Saam, N., & Sonnessa, M. (2006). A Common Protocol for Agent-Based Social Simulation. *Journal of Artificial Societies and Social Simulation*, *9*(1), 142–204.

Robinson, S. A., & Rai, V. (2015). Determinants of spatio-temporal patterns of energy technology adoption: An agent-based modeling approach. *Applied Energy*, *151*, 273–284.

https://doi.org/10.1016/j.apenergy.2015.04.071

Rosenbaum, M. E. (1986). The repulsion hypothesis: On the nondevelopment of relationships. *Journal of Personality and Social Psychology*, *51*(6), 1156–1166.

Rosenberg, M. J., Hovland, C. I., McGuire, W. J., Abelson, R. P., & Brehm, J. W. (1960). *Attitude organization and change: An analysis of consistency among attitude components. (Yales studies in attitude and communication.), Vol. III. Attitude organization and change: An analysis of consistency among attitude components. (Yales studies in attitude and communication.), Vol. III*. Oxford, England: Yale Univer. Press.

Rumelhart, D. E., & McClelland, J. L. (1986). *Parallel distributed processing: Explorations in the microstructure of cognition: Vol. 1. Foundations*. Cambridge, MA: MIT Press.

Rumelhart, D. E., Smolensky, P., McClelland, J. L., & Hinton, G. (1986). Schemata and sequential thought processes in PDP models. In D. E. Rumelhart & J. L. McClelland (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition (Vol. 2)* (pp. 7–57). Cambridge, MA: MIT Press.

Russo, J. E., Carlson, K. A., Meloy, M. G., & Yong, K. (2008). The goal of consistency as a cause of information distortion. *Journal of Experimental Psychology: General*. Russo, J. Edward: Johnson Graduate School of Management, Cornell University, Ithaca, NY, US, 14850-6201, jer9@cornell.edu: American Psychological Association. https://doi.org/10.1037/a0012786

Sander, D., Grandjean, D., & Scherer, K. R. (2005). A systems approach to appraisal mechanisms in emotion. *Neural Networks*, *18*(4), 317–352. https://doi.org/https://doi.org/10.1016/j.neunet.2005.03.001

Sapiezynski, P., Stopczynski, A., Lassen, D. D., & Lehmann, S. (2019). Interaction data from the Copenhagen Networks Study. *Scientific Data*, *6*(1), 1–10. https://doi.org/10.1038/s41597-019-0325-x

Saramäki, J., & Moro, E. (2015). From seconds to months: an overview of multi-scale dynamics of mobile telephone calls. *European Physical Journal B*, *88*(6). https://doi.org/10.1140/epjb/e2015-60106-6

Savage, L. (1954). *The Foundations of Statistics*. New York: Wiley.

Scholl, W. (2013). The socio-emotional basis of human interaction and communication: How we construct our social world. *Social Science Information*, *52*(1), 3–33. https://doi.org/10.1177/0539018412466607

Schröder, T., & Thagard, P. (2013). The affective meanings of automatic social behaviors: three mechanisms that explain priming. *Psychological Review*, *120*(1), 255–280. https://doi.org/10.1037/a0030972

Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental , hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, *48*, 39–49.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 25, pp. 1–65). New York: Academic Press.

Schwartz, Shalom H. (2012). An Overview of the Schwartz Theory of Basic Values. *Online Readings in Psychology and Culture*, *2*(1). https://doi.org/https://doi.org/10.9707/2307-0919.1116

Sekara, V., Stopczynski, A., & Lehmann, S. (2016). The fundamental structures of dynamic social networks. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(36), 10. https://doi.org/10.1073/pnas.1602803113

Shah, A. K., & Oppenheimer, D. M. (2008). Heuristics made easy: An effort-reduction framework. *Psychological Bulletin*. Shah, Anuj K.: Department of Psychology, Princeton University, Princeton, NJ, US, 08544, akshah@princeton.edu: American Psychological Association. https://doi.org/10.1037/0033-2909.134.2.207

Shank, D. B., & Lulham, R. (2016a). Products as Affective Modifiers of Identities. *Sociological Perspectives*, *60*(1), 186–205. https://doi.org/10.1177/0731121416629996

Shank, D. B., & Lulham, R. (2016b). Symbolic Interaction with Consumer Products: An Affect Control Theory Approach. *Sociology Compass*, *10*(7), 613–622.

Sherif, M., & Hovland, C. I. (1961). *Social Judgment: Assimilation and Contrast Effects in Communcation and Atttiude Change.* (Yale Univerity Press, Ed.). New Haven, CT.

Shiftan, Y., Outwater, M., & Zhou, Y. (2008). Transit market research using structural equation modeling and attitudinal market segmentation. *Transport Policy*, *15*, 186–195.

Simon, D., Krawczyk, D. C., Bleicher, A., & Holyoak, K. J. (2008). The transience of constructed preferences. *Journal of Behavioral Decision Making*, *21*, 1–14.

Simon, D., Snow, C. J., & Read, S. J. (2004). The redux of cognitive consistency theories: evidence judgments by constraint satisfaction. *Journal of Personality and Social Psychology*, *86*(6), 814–837. https://doi.org/10.1037/0022-3514.86.6.814

Simon, Dan, & Holyoak, K. J. (2002). Structural Dynamics of Cognition: From Consistency Theories to Constraint Satisfaction. *Personality and Social Psychology Review*, *6*(4), 283–294. https://doi.org/10.1207/S15327957PSPR0604_03

Simon, Dan, Krawczyk, D. C., & Holyoak, K. J. (2004). Construction of preferences by constraint satisfaction. *Psychological Science*, *15*(5), 331–336. https://doi.org/10.1111/j.0956-7976.2004.00678.x

Simon, Dan, Stenstrom, D. M., & Read, S. J. (2015). The Coherence Effect : Blending Cold and Hot Cognitions. *Journal of Personality and Social Psychology*, *109*(3), 369–394.

Simon, H. A. (1955). A behavioral model of rational choice. *The Quarterly Journal of Economics*, *69*(1), 99–118.

Simon, H. A. (1982). *Models of bounded rationality*. Cambridge, MA: MIT Press.

Simon, Herbert A. (2000). Bounded rationality in social science: Today and tomorrow. *Mind & Society*, *1*, 25–39. https://doi.org/10.1007/BF02512227

Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., … Tiwari, G. (2014). Transport. In R. Edenhofer, O., Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, … J. C. Minx (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovern- mental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA.: Cambridge University Press.

Sobkowicz, P. (2009). Modelling Opinion Formation with Physics Tools : Call for Closer Link with Reality. *Journal of Artificial Societies and Social Simulation*, *12*(1).

Spellman, B. a., Ullman, J. B., & Holyoak, K. J. (1993). A Coherence Model of Cognitive Consistency: Dynamics of Attitude Change During the Persian Gulf War. *Journal of Social Issues*, *49*(4), 147–165. https://doi.org/10.1111/j.1540-4560.1993.tb01185.x

Squazzoni, F. (2017). Towards a Complexity-Friendly Policy: Breaking the Vicious Circle of Equilibrium Thinking in Economics and Public Policy. In J. Johnson, A. Nowak, P. Ormerod, B. Rosewell, & Y.-C. Zhang (Eds.), *Non-Equilibrium Social Science and Policy* (pp. 135–148). Cham: Springer Nature. https://doi.org/10.1007/978-3-319-42424-8

Stanovich, K. E., & West, R. F. (2003). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences*, *26*(4), 527. https://doi.org/10.1017/S0140525X03210116

Steg, L., Perlaviciute, G., & van der Werff, E. (2015). Understanding the human dimensions of a sustainable energy transition. *Frontiers in Psychology*, *6*(805). https://doi.org/10.3389/fpsyg.2015.00805

Stroebe, W., & Hewstone, M. (2014). Strategien zur Einstellungs- und Verhaltensveränderung. In W. Stroebe & M. Hewstone (Eds.), *Sozialpsychologie* (pp. 231–268). Berlin, Heidelberg: Springer Verlag. Retrieved from https://doi.org/10.1007/978-3-642-41091-8

Stryker, S. (1980). *Symbolic Interactionism: A Social Structural Version*. Menlo Park, CA: Benjamin Cummings.

Sun, R. (2012). *Grounding social sciences in cognitive sciences*. MIT Press.

Thagard, P., & Millgram, E. (1995). Inference to the best plan: A coherence theory of decision. In A. Ram & D. B. Leake (Eds.), *Goal-driven learning* (pp. 439–454). Cambridge, MA: MIT Press.

Thagard, Paul. (1989). Explanatory Coherence. *Behavioral and Brain Sciences*, *12*(3), 435–502.

Thagard, Paul. (2000). *Coherence in thought and action*. Cambridge, MA: MIT Press.

Thagard, Paul. (2003). Why wasn't O.J. convicted? Emotional coherence in legal inference. *Cognition & Emotion*, *17*(3), 361–383.

Thagard, Paul. (2006). *Hot thought: Mechanisms and applications of emotional cognition*. Cambridge, MA: MIT Press.

Thagard, Paul, & Kroon, F. W. (2006). Emotional consensus in group decision making. *Mind & Society*, *5*(1), 85–104.

Thagard, Paul, & Verbeurgt, K. (1998). Coherence as Constraint Satisfaction. *Cognitive Science*, *22*(1), 1–24. https://doi.org/10.1207/s15516709cog2201_1

Thøgersen, J. (2014). Social Marketing in Travel Demand Management. In T. Gärling, D. Ettema, & M. Friman (Eds.), *Handbook of Sustainable Travel*. Dordrecht: Springer. https://doi.org/https://doi.org/10.1007/978-94-007-7034-8_8

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, *185*(4157,), 1124–1131. https://doi.org/10.1126/science.185.4157.1124

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, *211*(4481), 453 LP – 458. https://doi.org/10.1126/science.7455683

UBA. (2020). Emissionsquellen. Retrieved February 5, 2021, from https://www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen/emissionsquellen#energie-stationar

Valente, T. W. (1995). *Network models of the diffusion of innovations*. Cresskill, NJ: Hampton Press.

Valente, T. W. (2005). Network Models and Methods for Studying the Diffusion of Innovations. In P. Carrington, J. Scott, & S. Wasserman (Eds.), *Models and Methods in Social Network Analysis* (pp. 98–116). New York, New York: Cambridge University Press.

Verkehrswende, A. (2017). *Mit der Verkehrwende die Mobilität von morgen sichern. 12 Thesen zur Verkehrswende*. Berlin. Retrieved from https://www.agora-verkehrswende./fileadmin/Projekte/2017/12_Thesen/Agora-Verkehrswende-12-Thesen_WEB.pdf

Volz, K. G., & Hertwig, R. (2016). Emotions and Decisions: Beyond Conceptual Vagueness and the Rationality Muddle. *Perspectives on Psychological Science*, *11*(1), 101–116.

https://doi.org/10.1177/1745691615619608

Von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton, NJ, US: Princeton University Press.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt. II. *Psychologische Forschung*, *4*, 301–350. https://doi.org/10.1515/gth-2017-0007

Windrum, P., Fagiolo, G., & Moneta, A. (2007). Empirical validation of agent-based models: Alternatives and prospects. *Journal of Artificial Societies and Social Simulation*, *10*(2), 8. Retrieved from http://jasss.soc.surrey.ac.uk/10/2/8.html

Wolf, I. (2016). The Interaction Between Humans and Autonomous Agents. In M. Maurer, J. C. Gerdes, B. Lenz, & H. Winner (Eds.), *Autonomous Driving: Technical, Legal and Social Aspects* (pp. 103–124). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-48847-8_6

Wolf, I., & de Haan, G. (2013). Der simulierte Kunde - Computerbasierte Marktanalyse am Beispiel von Elektromobilität. In J. Gausemaier (Ed.), *Vorausschau und Technologieplanung, 9. Symposium für Vorausschau und Technologieplanung* (pp. 279–300). Berlin: Vorausschau und Technologieplanung, 9. Symposium für Vorausschau und Technologieplanung.

Wolf, I., Röhr, V., & Schröder, T. (2017). Election data can inform simulations of innovation perception. In *Proceedings of the 2017 Social Simulation Conference*.

Zhou, J. (2016). Boomerangs versus Javelins: How Polarization Constrains Communication on Climate Change. *Environmental Politics*, *25*(5), 788–811. https://doi.org/10.1080/09644016.2016.1166602

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertation selbstständig und ohne unerlaubte Hilfe angefertigt habe.

Zudem versichere ich, dass ich mich zu keinem Zeitpunkt in der Vergangenheit anderwärts um einen Doktorgrad beworben habe und auch keinen Doktorgrad in dem Promotionsfach Erziehungswissenschaften oder Psychologie besitze.

Kleinmachnow, 31.05.2021

Ingo Wolf

Abbildungsverzeichnis

Abbildung 1: Mehrebenenmodell und Studienübersicht.. 28

Figure 1. Correlation between prior attitudes and vignette responses 42
Figure 2. Mean ratings on all vignette responses across conditions 43
Figure 3. Parallel constraint satisfaction model (PCS) of attitude formation and change 45
Figure 4. Computational model results. 49
Figure 5. HOTCO emotional constraint network of transport mode decisions........................... 105
Figure 6. Illustration of the agent-based model InnoMind communication process 110
Figure 7. Districts map of Berlin.. 114
Figure 8. Diffusion of preferred modes of transport 118
Figure 9. Diffusion of E-Vehicles in Reference case, Zero-emission-zone, Tax exemption and Purchase subsidy scenarios separated by clusters 119
Figure 10. Diffusion of E-Vehicles in Reference case, Zero-emission-zone, Tax exemption and Purchase subsidy 121
Figure 11. Connectionist InnoMind agent architecture 138
Figure 12. Geographically explicit social network model in InnoMind.. 144
Figure 13. Flowchart of simulations with InnoMind.. 148
Figure 14. Simulation results (main effects) 150
Figure 15. Comparative change in transportation preferences after different carsharing campaigns suggested by simulations with InnoMind. 151
Figure 16. Simulation results (interaction effects) 152

Tabellenverzeichnis

Tabelle 1: Dimensionen und Ausprägungen der Vignetten ... 32

Table 1. Evaluation ratings of transport modes for each segments and total sample ... 69
Table 2. Potency ratings of transport modes for each segments and total sample ... 70
Table 3. Activity ratings of transport modes for each segments and total sample ... 71
Table 4. Sociodemographic characteristics of each segment and of the total sample ... 75
Table 5. Indicators of travel behavior for each segment and the total sample ... 79
Table 6. Adoption intention of various sustainable transport innovations of each segment ... 81
Table 7. Sociodemographic characteristics, travel behavior and preferences of mobility types ... 106
Table 8. Odd ration and their related score statistics of binary logistic regression analysis ... 113
Table 9. Transportation needs in the InnoMind agent-based model ... 139
Table 10. Sample survey questions for parametrization of InnoMind agents ... 141
Table 11. Simulated carsharing campaigns and their computational implementation ... 147