RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Energy Systems and Environment

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Doctoral Student of the Study Programme "Environmental Science"

METHODOLOGY FOR SOCIO-TECHNICAL TRANSITION RESEARCH

Summary of the Doctoral Thesis

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFFIC DEGREE OF DOCTOR OF ENVIRONMENTAL EGINEERING

To be granted the scientific degree of Doctor of Environmental Engineering (*Dr. sc. ing.*), the defence of the present Doctoral Thesis will take place on 30th of August, 2017 at 2 p.m., at the Faculty of Power and Electrical Engineering of Riga Technical University, 12/1 Azenes Street, Room 115.

OFFICAL REVIEWERS

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Environmental Engineering is my own and does not contain any unacknowledged material from any source. I confirm that the present Doctoral Thesis has not been submitted to any other university for the promotion to other scientific degree.

Lelde Timma ……………………………….. (signature)

Date ………………………..

The present Doctoral Thesis has been written in English and contains: introduction, 3 chapters, conclusions, bibliography with 79 reference sources; it has been illustrated by 17 figures and 6 tables. The volume of the Thesis is 134 pages including 6 appendices.

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The work has been supported by the National Research Program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

Topicality of the Doctoral Thesis

As the response to the financial downturn and arising social problems, eco-innovation flagship was elaborated as one of the main building blocks for sustainable, smart and inclusive growth. Nevertheless, the experts are increasingly pointing out that one important link is missing – while focusing mainly on technical innovations and natural environment, social aspect is mostly disregarded. The social aspect includes human, economic, policy, organisational and other interactions in the system. By bringing together these three sectors – social, technical and natural environment –, the author of the present Thesis studied so the called socio-technical system.

Currently, the studies using social and technical aspects for the research on transition processes are fragmented, both in terms of studied sectors, used methods, and scientific fields. Especially, in the field of energy research, the majority of the works study techno-economic aspects of the system, while only few attempts have been made to incorporate socio-technical perspective as well.

Also a clear lack of a holistic methodology has been identified, therefore the ultimate aim of this Thesis is to attempt to link the engineering and social science study field to create such modelling approach. The Thesis work, therefore, guides through the path of the creation of this methodology. As a case study object, the household sector is used in the Thesis. The complexity of the applied methods was developed over time to match the growing complicatedness of studied research questions.

The author of this Thesis views the socio-technical transition processes from the perspective of various sectors, such as energy use, production and management, innovation diffusion, and others. Also, the transitions are looked from the scientific lenses of various possible methods and their combination. And, last but not least, these transition studies are considered from the perspective of various scientific fields, both engineering and social science.

The Aim and Tasks of the Doctoral Thesis

The aim of the present Doctoral Thesis is to develop, apply and evaluate a holistic methodology to study socio-technical transitions. The complexity of the applied methods was developed over time to match the growing complicatedness of studied research questions. The following tasks were set to achieve the aim:

1) to study socio-technical transitions in the field of energy efficiency and conservation;
2) to study socio-technical transitions in the field of eco-innovation diffusion;
3) to develop and evaluate the single mixed modelling approach for socio-technical transitions on case study;
4) to develop and evaluate the multiple mixed modelling approach for socio-technical transitions on a case study;
5) to develop and evaluate the hybrid modelling approach for socio-technical transitions on a case study.

Scientific Significance

In this Thesis, two major points of scientific significance can be viewed. Firstly, the development of socio-technical transition research in the field of energy and environmental protection. Nowadays, experts are increasingly pointing out that one important link is missing; while focusing mainly on technical innovations and natural environment, social aspect is mostly disregarded. This work, therefore, expands the current knowledge in the field of socio-technical transitions by analysing the causes of social and technological changes. This Thesis addresses how these transitions originate, unfold, and finish.

Secondly, the Thesis presents a complex study where novel modelling methodology is developed. The presented methodology combines the aspects of technical and social systems and natural environment, thus providing holistic methodology tools to study socio-technical transitions. The developed methodology contains various levels of complexity, starting with the use of single mixed methodology up to hybrid modelling tools, containing four methods (social psychology, statistical data analysis, system dynamics, and artificial intelligence).

As to the author's knowledge, this is the first time that socio-technical transitions are studied by using the latest knowledge and advanced modelling tools for the engineering and social science field together. Also the development of methodology that uses both white-box models (system dynamics) in combination with black-box models (artificial intelligence) is an important aspect contributing to the development of state-of-the-art modelling tools.

Practical Significance

Currently, the mitigation of climate change does not take the most effective path, since various eco-innovations and energy efficiency solutions have already reached a mature state, but they diffuse slowly into the market. Therefore, in this Thesis, the developed methods for socio-technical transitions are approbated in two study domains: (1) eco-innovations diffusion, and (2) energy efficiency and conservation.

As practical applicability for these sectors, policy interventions were offered to move towards greater sustainability. Thus, by using presented frameworks, policy makers can analyse the past trends, for example, in the diffusion of lighting technologies, identify bottlenecks and thus test various policy tools to foster the market up-take of more energy-efficient lighting solutions. Moreover, in the presented framework, also the human behaviour is taken into the account, thus increasing the reliability of obtained simulation results. These outlined methods thus can guide the decision-making process and model the outcomes of various development scenarios. By applying the knowledge obtained, the sectors can be targeted more effectively to reach a sustainable development goal.

The present Doctoral Thesis allows transferring the developed methodology to study other technologies and services at different levels of the economy. The methodology developed can be of practical applicability for academic research, and for policy makers and for entrepreneurs and investors as well.

Approbation of the Study

The research results have been approbated in 12 international scientific conferences and published as 25 full-length articles (19 in *Scopus* database and 15 in *ISI Web of Science* database) and one abstract in international scientific journals and conference proceedings.

Reports at International Scientific Conferences

1. Timma L., Blumberga A., Bazbauers G., Blumberga D. Novel Tools to Study Socio-Technical Transitions in Energy Systems // International Scientific Conference of Environmental and Climate Technologies CONECT 2017, 10–12 May 2017, Riga, Latvia.

2. Timma L., Bariss U., Dandens A., Blumberga A., Blumberga D. Framework for the Assessment of Household Electricity Saving by Integrating Behavioural Aspects // International Scientific Conference of Environmental and Climate Technologies CONECT 2015, 14–16 October 2015, Riga, Latvia.

3. Timma L., Bariss U., Blumberga A., Blumberga D. Outlining Innovation Diffusion Processes in Households using System Dynamics. Case Study: Energy Efficiency Lighting // 7th International Conference on Applied Energy, ICAE 2015; 28–31 March 2015, Abu Dhabi, United Arab Emirates.

4. Timma L., Blumberga A., Blumberga D. Understanding the Technological Substitution by Hybrid Modelling Practice: A Methodological Approach // 18th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction PRES 2015, 23–27 August 2015, Kuching, Malaysia.

5. Blumberga A., Timma L., Lauka D., Dace E., Barisa A., Blumberga D. Achieving Sustainability in Non-ETS Sectors using System Dynamics Modelling Practice // 18th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction PRES 2015, 23–27 August 2015, Kuching, Malaysia

6. Timma L., Blumberga A., Blumberga D. Combined and Mixed Methods Research in Environmental Engineering: When Two is Better than One // International Scientific Conference of Environmental and Climate Technologies CONECT 2014, 14–16 October 2014, Riga, Latvia.

7. Blumberga A., Timma L., Vilgerts J., Blumberga D. Assessment of Sustainable Collection And Recycling Policy of Lead-Acid Accumulators from the Perspective of System Dynamics Modelling // 17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction PRES 2014, 23–27 August 2014, Prague, Czech Republic.

8. Timma L., Vilgerts J., Vanaga R., Kļavenieks K., Blumberga D. Decomposition Analysis Based on IPAT and Kaya Identity for Assessment of Hazardous Waste Flow Within Enterprise // 27th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy System, ECOS 2014, 15–19 June, 2014, Turku, Finland.

9. Timma L., Blumberga D. Index Decomposition Analysis for Energy Sectors in Latvia // 6th International Conference on Applied Energy, ICAE 2014, 30 May – 2 June, 2014, Taipei, Taiwan.

10. Bariss U., Timma L., Blumberga D. Smart Metering Pilot Project Results // 6th International Conference on Applied Energy, ICAE 2014, 30 May – 2 June, 2014, Taipei, Taiwan.

11. Vilgerts J., Timma L., Romagnoli F., Blumberga A., Blumberga D. A System Dynamics Model for the Assessment Of Hazardous Waste Management System. Case Study: Waste Batteries and Accumulators // 8th Conference on Sustainable Development of Energy, Water and Environmental Systems, SDEWES 2013, 22–27 September, 2013, Dubrovnik, Croatia.

12. Vilgerts J., Timma L., Blumberga D. A Methodology for Quantification of Hazardous Waste Flows: Case Study for the Baltic States (Estonia, Latvia, Lithuania) // 13th International Conference on Environmental Science and Technology, 5–7 September 2013, Athens, Greece.

13. Vilgerts J., Timma L., Blumberga D. A Forecast Model for Projecting the Amount of Hazardous Waste // International Conference on Waste Management (ICWM 2013), 13–14 May 2013, Copenhagen, Denmark.

14. Vilgerts J., Timma L., Blumberga D. A Methodology for Forecasting Hazardous Waste Flows // 7th International Conference on the Impact of Environmental Factors on Health "Environmental Health Risk VII", 23–25 April 2013, Budapest, Hungary.

Publications on the Topic of the Doctoral Thesis

1. Timma L., Blumberga A., Bazbauers G., Blumberga D. Novel Tools to Study Socio-Technical Transitions in Energy Systems // Accepted in Energy Procedia on International Scientific Conference of Environmental and Climate Technologies CONECT 2017. p. 4 *(Pending in Scopus and ISI Web of Science).*

2. Timma L., Bazbauers G., Bariss U., Blumberga A., Blumberga D. Energy Efficiency Policy Analysis Using Socio-Technical Approach and System Dynamics. Case Study of Energy Efficient Lighting in Households // Accepted for publication in the Journal of Energy Policy http://dx.doi.org/10.1016/ j.enpol.2017.07.030 *(Pending in Scopus and ISI Web of Science).*

3. Timma L., Zoss T., Blumberga D. Life after the Financial Crisis. Energy Intensity and Energy Use Decomposition on Sectorial Level in Latvia // Applied Energy (ISSN: 0306-2619) – 2016 – Vol. 162 – pp. 1586–1592. doi: 10.1016/ j.apenergy.2015.04.021 *(In Scopus and ISI Web of Science).*

4. Muizniece I., Timma L., Blumberga D. Biotechonomy Innovations Development Barriers in Latvia // Energy Procedia on International Scientific Conference of Environmental and Climate Technologies, CONECT 2016 (ISSN: 1876-6102) – 2017 – Vol. 113 – pp. 285–288. doi.org/10.1016/ j.egypro.2017.04.067 *(Pending in Scopus and ISI Web of Science).*

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7. Timma L., Bariss U., Dandens A., Blumberga A., Blumberga D. Framework for the Assessment of Household Electricity Saving by Integrating Behavioural Aspects // Energy Procedia on International Scientific Conference of Environmental and Climate Technologies, CONECT 2015 (ISSN: 1876-6102) – 2016 – Vol. 95 – pp. 517–521. doi.org/10.1016/j.egypro.2016.09.078 *(In Scopus and ISI Web of Science).*

8. Vīgants E., Blumberga A., Timma L., Ījabs I., Blumberga D. The Dynamics of Technological Substitution: The Case of Eco-Innovation Diffusion of Surface Cleaning Products // Journal of Cleaner Production (ISSN: 0959-6526) – 2016 – Vol. 132 – pp. 279–288. doi: 10.1016/j.jclepro.2015.10.007 *(In Scopus and ISI Web of Science).*

9. Bazbauers G., Bariss U., Timma L., Lauka D., Blumberga A., Blumberga D. Electricity Saving in Households due to the Market Liberalization and Change in the Consumer Behaviour // Energetika (ISSN: 0235-7208) – 2015 – Vol. 61 – pp. 108–118. doi: 10.6001/energetika.v61i3-4.3251 *(In Scopus).*

10. Timma L., Bariss U., Blumberga A., Blumberga D. Outlining Innovation Diffusion Processes in Households Using System Dynamics. Case Study: Energy Efficiency Lighting // Energy Procedia on Clean, Efficient and Affordable Energy for a Sustainable Future (ISSN: 1876-6102) – 2015 – Vol. 75 – pp. 2859–2864. doi: 10.1016/j.egypro.2015.07.574. *(In Scopus and ISI Web of Science).*

11. Timma L., Blumberga A., Blumberga D. Understanding the Technological Substitution by Hybrid Modelling Practice: A Methodological Approach // Chemical Engineering Transactions on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (ISSN: 1974-9791) – 2015 – Vol. 45 – pp. 379–384. doi: 10.3303/CET1545064 *(In Scopus and ISI Web of Science).*

12. Blumberga A., Timma L., Lauka D., Dace E., Barisa A., Blumberga D. Achieving Sustainability in Non-ETS Sectors Using System Dynamics Modelling Practice // Chemical Engineering Transactions on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (ISSN: 1974-9791) – 2015 – Vol. 45 – pp. 871–876. doi: 10.3303/ CET1545146 *(In Scopus and ISI Web of Science).*

13. Bariss U., Dandens A., Timma L., Blumberga A. Blumberga D. How to Assess Involvement of Electricity End User in Energy Efficiency Improvement – Analysis of Survey Results // Energy Procedia on International Scientific Conference of Environmental and Climate Technologies, CONECT 2014 (ISSN: 1876-6102) – 2015 – Vol. 72 – pp. 270–277. doi: 10.1016/j.egypro. 2015.06.039 *(In Scopus and ISI Web of Science).*

14. Timma L., Blumberga A., Blumberga D. Combined and Mixed Methods Research in Environmental Engineering: When Two is Better Than One // Energy Procedia on International Scientific Conference of Environmental and Climate Technologies, CONECT 2014 (ISSN: 1876-6102) – 2015 – Vol. 72 – pp. 300–306. doi: 10.1016/j.egypro.2015.06.043 *(In Scopus and ISI Web of Science).*

15. Blumberga A., Timma L., Romagnoli F., Blumberga D. Dynamic Modelling of a Collection Scheme of Waste Portable Batteries for Ecological and Economic Sustainability // Journal of Cleaner Production (ISSN: 0959-6526) – 2015 – Vol. 88 – pp. 224–233. doi: 10.1016/j.jclepro.2014.06.063 *(In Scopus and ISI Web of Science).*

16. Lauka D., Blumberga A., Blumberga D., Timma L. Analysis of GHG Reduction in Non-ETS Energy Sector // Energy Procedia on Clean, Efficient and Affordable Energy for a Sustainable Future (ISSN: 1876-6102) – 2015 – Vol. 75 – pp. 2534–2540. doi: 10.1016/j.egypro.2015.07.280 *(In Scopus and ISI Web of Science).*

17. Timma L., Vilgerts J., Vanaga R., Kļavenieks K., Blumberga D. Decomposition Analysis Based on IPAT and Kaya Identity for Assessment of Hazardous Waste Flow within Enterprise // Proceedings of the 27th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy System, ECOS 2014 – Code 109102 – pp. 1–7. doi: 10.13140/RG.2.1.4450.0888 *(In Scopus).*

18. Bariss U., Timma L., Blumberga D. Smart Metering Pilot Project Results // Energy Procedia on Clean, Efficient and Affordable Energy for a Sustainable Future (ISSN: 1876-6102) – 2014 – Vol. 61 – pp. 2176–2179. doi: 10.1016/j.egypro.2014.12.103 *(In Scopus).*

19. Blumberga A., Timma L., Vilgerts J., Blumberga D. Assessment of Sustainable Collection and Recycling Policy of Lead-Acid Accumulators from the Perspective of System Dynamics Modelling // Chemical Engineering Transactions on PRES 2014, 17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (ISSN: 1974-9791) – 2014 – Vol. 39 – pp. 649–654. doi: 10.3303/CET1439109 *(In Scopus and ISI Web of Science).*

20. Blumberga D., Cimdina G., Timma L., Blumberga A., Rosa M. Green Energy Strategy 2050 for Latvia: A Pathway Towards a Low Carbon Society // Chemical Engineering Transactions on PRES 2014, 17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (ISSN: 1974-9791) – 2014 – Vol. 39 – pp. 1507–1512. doi: 10.3303/CET1439252 *(In Scopus and ISI Web of Science).*

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22. Vilgerts J., Timma L., Romagnoli F., Blumberga A., Blumberga D. A System Dynamics Model for the Assessment of Hazardous Waste Management System. Case Study: Waste Batteries and Accumulators // Conference Proceedings of 8th Conference on Sustainable Development of Energy, Water and Environmental Systems (ISSN: 1847-7178) – 2013 – Paper ID: 0508 – pp. 1–12.

23. Vilgerts J., Timma L., Romagnoli F., Blumberga A., Blumberga D. A System Dynamics Model for the Assessment of Hazardous Waste Management System. Case Study: Waste Batteries and Accumulators // Abstract of 8th Conference on Sustainable Development of Energy, Water and Environmental Systems – 2013 – Paper ID: 0508 – 1 p.

24. Vilgerts J., Timma L., Blumberga D. A Methodology for Quantification of Hazardous Waste Flows: Case Study for the Baltic States (Estonia, Latvia, Lithuania) // Proceedings of the 13th International Conference on Environmental Science and Technology (ISSN: 1106-5516) – 2013 – pp. 1–8. doi: 10.13140/RG.2.1.2959.1443 *(In ISI Web of Science).*

25. Vilgerts J., Timma L., Blumberga D. A Forecast Model for Projecting the Amount of Hazardous Waste // World Academy of Science, Engineering and Technology (ISSN: 2010-376X) – 2013 – Vol. 78 – pp. 502–505.

26. Vilgerts J., Timma L., Blumberga D. A methodology for Forecasting Hazardous Waste Flows // WIT Transactions on Biomedicine and Health (ISSN: 1743-3525) – 2013 – Vol. 16 – pp. 227–236. doi: 10.2495/EHR130191 *(In Scopus).*

Other Publications

1. Timma L., Blumberga D. The Improvements of Performance Reliability in Solar Combisystem by the Application of Artificial Intelligence // Chemical Engineering Transactions on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (ISSN: 1974-9791) – 2015 – Vol. 45 – pp. 1237–1242. doi: 10.3303/CET1545207 *(In Scopus and ISI Web of Science).*

2. Timma L., Blumberga D. An Algorithm for the Selection of Structure for Artificial Networks. Case Study: Solar Thermal Energy Systems // Energy Procedia on International Scientific Conference Environmental and Climate Technologies, CONECT 2014 (ISSN: 1876-6102) – 2015 – Vol. 72 – pp. 135–141. doi: 10.1016/j.egypro.2015.06.019 *(In Scopus and ISI Web of Science).*

3. Blumberga A., Timma L., Blumberga D. System Dynamic Model for the Accumulation of Renewable Electricity using Power-to-Gas and Power-to-Liquid Concepts // Environmental and Climate Technologies (ISSN: 2255-8837) – 2015 – Vol. 16 (1) – pp. 54–68. doi: 10.1515/rtuect-2015-0012 *(In Scopus).*

4. Cimdina G., Timma L., Veidenbergs I., Blumberga D. Methodologies Used for Scaling-up From a Single Energy Production Unit to State Energy Sector // Environmental and Climate Technologies (ISSN: 2255-8837) – 2015 – Vol. 15 (1) – pp. 5–21. doi: 10.1515/rtuect-2015-0002 *(In Scopus).*

5. Timma L., Sams K., Valtere S., Vilgerts J., Blumberga D. Full Factorial Design on Screening Experiments for Biosurfactant Enhanced Remediation of Hydrophobic Substances in Soil // Journal of Clean Technologies (ISSN: 1793-821X) – 2014 – Vol. 2 (1) – pp. 51–56. doi: 10.7763/JOCET.2014.V2.90.

6. Timma L., Blumberga D. Detection of Abrupt and Incipient Faults in Solar Combisystems with Artificial Neural Networks // International Scientific Conference of Environmental and Climate Technologies: Abstract Book (ISBN 978-9934-8302-8-0) – 2013 – 17 p.

7. Timma L., Blumberga D. Application of Artificial Neural Networks for Detection of Developing Faults in Solar Combisystems // Conference Proceedings of 8th Conference on Sustainable Development of Energy, Water and Environmental Systems (ISSN: 1847-7178) – 2013 – pp. 1–12.

8. Timma L., Blumberga D. Application of Artificial Neural Networks for Detection of Developing Faults in Solar Combisystems // Abstract of 8th Conference on Sustainable Development of Energy, Water and Environmental Systems – 2013 – 1 p.

9. Vilgerts J., Timma L., Blumberga A., Blumberga D., Slisane Dz. Application of System Dynamic Model for the Composting of Petroleum Contaminated Soil under Various Policies // Agronomy Research (ISSN: 1406-894X) – 2013 – Vol. 11 – pp. 391–404. *(In Scopus and ISI Web of Science).*

10. Timma L., Sams K., Valtere S., Vilgerts J., Blumberga D. Biosurfactants Enhanced Remediation of Historically Contaminated, Multiple Fraction Soil // Conference Proceedings on 2nd Edition of the International Conference and Exhibition WASTES "Solutions, Treatments and Opportunities" (ISSN: 2183-0568) – 2013 – pp. 721–726. doi: 10.13140/RG.2.1.4904.7445.

11. Zandeckis A., Timma L., Blumberga D., Rochas C., Rosa M. Solar and Pellet Combisystem for Apartment Buildings: Heat Losses and Efficiency Improvements of the Pellet Boiler // Applied Energy (ISSN: 0306-2619) – 2013 – Vol. 101 – pp. 244–252. doi: 10.1016/j.apenergy.2012.03.049 *(In Scopus and ISI Web of Science).*

Monographies and Methodological Material

1. Blumberga D., Barisa A., Kubule A., Kļaviņa K., Lauka D., Muižniece I., Blumberga A., Timma L. Biotechonomy (original title in Latvian – "Biotehonomika") // Riga Technical University Press (ISBN: 978-9934-10-747-4) – 2016 – 338 p.

2. Blumberga D., Veidenbergs I., Blumberga A., Dāce E., Gušča J., Rošā M., Romagnoli F., Pubule J., Barisa A., Timma L., Bāliņa K., Kļaviņa K., Kubule A., Lauka D., Muižniece I., Kalnbaļķīte A. Kārkļina I., Prodaņuks T. Biotechonomy. Methodological Material (original tile in Latvian – "Biotehonomika. Metodiskais materiāls") // Riga Technical University Institute of Energy Systems and Environment – 2016 – 84 p.

3. Blumberga D., Gedrovičs M., Kirsanovs V., Timma L., Kļaviņa K., Kubule A., Kļaviņš J., Muižniece I., Kauls O., Barisa A., Bāliņa K., Lauka D., Ziemele J., Kārkliņa I. Laboratory Works for Students of Environmental Engineering, Vol. 3 (original title in Latvian – "Laboratorijas darbu krājums vides inženierzinātņu studentiem. 3. daļa") // Riga Technical University Press (ISBN: 978-9934-10-747-4) – 2016 – 92 p.

4. Blumberga D., Veidenbergs I., Valtere S., Gedrovičs M., Bažbauers G., Blumberga A., Žandeckis A., Žogla G., Kalniņš S. N., Laicāne I., Beloborodko A., Kirsanovs V., Timma L., Muižniece I., Kļaviņa K., Lauka D. Laboratory Works for Students of Environmental Engineering, Vol. 2 (original title in Latvian – "Laboratorijas darbu krājums vides inženierzinātņu studentiem. 2. daļa") // Riga Technical University Press (ISBN: 978-9934-10-595-1) – 2015 – 120 p.

Thesis Outline

The Doctoral Thesis is based on the thematically unified six scientific publications. Those publications are published in various scientific periodicals, and are accessible in scientific information repositories and cited international databases. The goal of these publications is to transfer and approbate the framework of socio-technical transitions.

This Thesis consists of an introduction and three chapters:

1) literature review,
2) research methodologies,
3) results and discussion thereof.

In the introduction, the goal of the Thesis and the underlying tasks are given, followed by the definition of the Thesis's structure and a short description of the approbation of the results obtained by means of the publications and participation in international scientific conferences.

Chapter 1 provides an overview of the research questions present in the defined study domains. Chapter 2 describes the methodologies used in the socio-technical transition studies. The results obtained from the application of the proposed methodologies are presented in Chapter 3. Finally, conclusions are given at the end of the Thesis.

1 SHORT DESCRIPTION OF THE SOLUTIONS USED

As the response to the financial downturn and arising social problems, eco-innovation flagship was elaborated as one of the main building blocks for sustainable, smart and inclusive growth of society[1]. Nevertheless, the experts are increasingly pointing out that one important link is missing – while focusing mainly on technical innovations and natural environment, social aspect is mostly disregarded[2]. This social aspect includes human, economic, policy, organisational, and other interactions in the system. By bringing together these three sectors – social environment, technical environment, and natural environment –, the author of the present Thesis studied the so called socio-technical system (see Fig. 1).

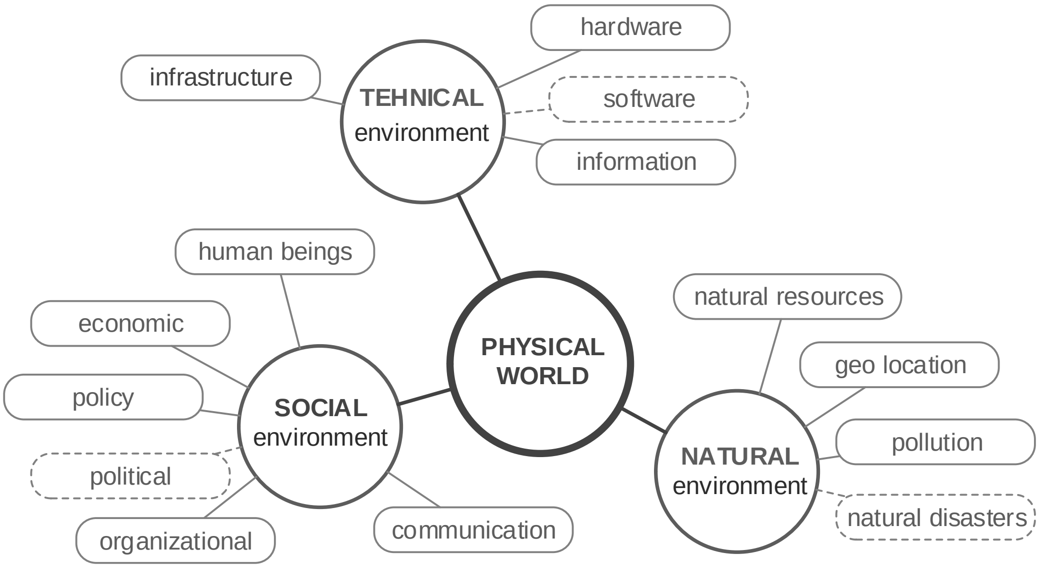

Fig. 1. Hierarchy of socio-technical systems adopted from Wu et al. (2015)[2].

The research on the socio-technical transitions analyses the causes of social and technological changes, where the main study questions are how these transitions originate, unfold, and finish. Here, the first challenge is to replicate and study historical transitions, and the second challenge is to develop tools for the analysis and finally propose the policy interventions[3].

In the Thesis, the contribution to socio-technical transitions in the households sector addressed all these challenges. Firstly, by studying the historical transitions in two domains of energy efficiency and eco-innovations (other domains, such as waste management, climate change mitigation, etc., have also been studied, and the references

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[1] EC, Innovation for a sustainable Future – The Eco-innovation Action Plan (Eco-AP), COM (2011) 899 final, 15.12.2011., Brussels.

[2] Wu P. P. Y., Fookes C., Pitchforth J., Mengersen K. (2015). A framework for model integration and holistic modelling of socio-technical systems. Decision Support Systems, 71, 14–27.

[3] Papachristos G., & Adamides E. (2016). A retroductive systems-based methodology for socio-technical transitions research. Technological Forecasting & Social Change, 108, 1–14.

to these studies are given in the publications' list, but the publications are not included as full papers in the Thesis work in order to focus on the most recent scientific work) and by proposing policy interventions for these studied systems. Secondly, by developing and refining the novel tools to study the transition processes.

In the Thesis, the complexity of the applied methods was developed over time to match the growing complicatedness of studied research questions (see Fig. 2).

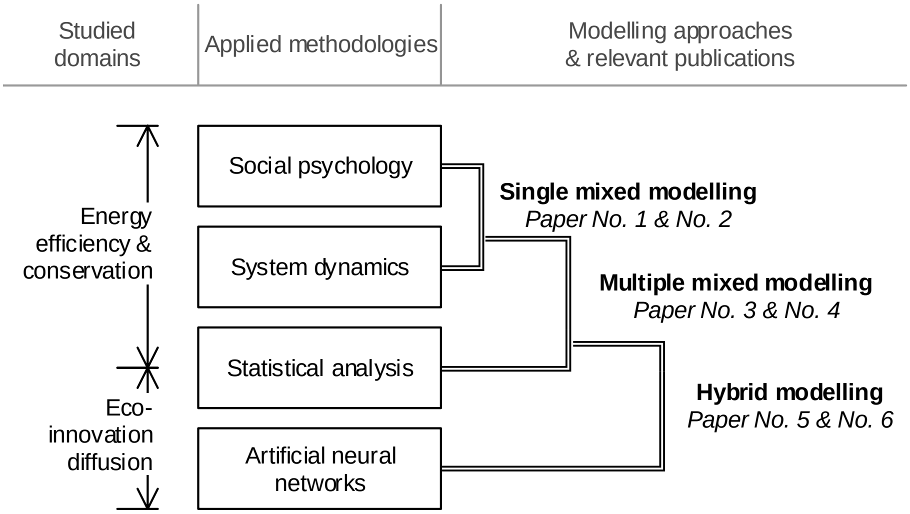

Fig. 2. The publications used to study socio-economic transitions (the full title of each publication corresponds to the number given in Table 1).

The work starts by the use of the social psychology and system dynamics models to study the transition of energy efficiency and conservation solutions in the households. Here, the presence of the aspects from social psychology were identified and implemented in the system dynamics model (see Papers No. 1 and No. 2). Next, the methodology was upgraded with statistical data analysis.

Nevertheless, energy efficiency improvements for a specific technology are always limited; therefore, the socio-technical transitions for fundamentally different products are also under the interest. In this Thesis, the technological substitution of current products with eco-innovation is studied in Paper No. 4 using the methodology developed by the Thesis' author. This presented methodology links statistical data analysis tools with the system dynamics model and uses social psychology to explain the obtained results, thus combining three methods including both social and technical aspects.

In the Thesis, the author goes even further and adds the fourth method – an artificial intelligence modelling tool – to the previously developed and tested algorithm, thus creating a hybrid or grey modelling tool for eco-innovation diffusion studies (see Paper No. 5). This grey modelling tool is used to describe eco-innovation diffusion with a higher accuracy than that of the models developed so far (see Paper No. 6). In the Thesis, the author refers to the above-mentioned six major publications – Papers Nos 1–6, which correspond to the articles given in Table 1.

Table 1. The publications used in the Thesis to study the socio-technical transitions

	Studied domain	No.	Title of publication
1	System Dynamics & Social Psychology or **Single mixed modelling approach**	1	*Framework for the assessment of household electricity saving by integrating behavioural aspects*
		2	*Electricity saving in households due to the market liberalization and change in the consumer behaviour*
2	Statistical Analysis & System Dynamics & Social Psychology or **Multiple mixed modelling approach**	3	*Energy efficiency policy analysis using socio-technical approach and system dynamics. Case study of energy efficient lighting in households*
		4	*The dynamics of technological substitution: the case of eco-innovation diffusion of surface cleaning products*
3	Statistical Analysis & System Dynamics & Social Psychology & Artificial intelligence or **Hybrid modelling approach**	5	*Combined and mixed methods research in environmental engineering: when two is better than one*
		6	*Understanding the technological substitution by hybrid modelling practice: a methodological approach*

1.1 Energy Efficiency and Conservation

Energy efficiency at the final consumers is one of the priorities for energy sustainability, where households are one of the major energy end-consumers. Therefore, various studies focus on smart metering, for example, Laicane et al. (2015)[4] anticipates electricity savings by 13 % until 2020 in the households with smart meters in Latvia.

In the analysed literature, research has been done on policies and programs to target households, but there is lack of studies that model the significance of behavioural aspects. **Therefore, the aim of Paper No. 1 is to search for the major behavioural aspects of electricity savings in households**. This study continues the research by Bariss, Timma & Blumberga (2014)[5] attempting to solve energy reduction causes including the households' behaviour.

Since the behaviour of single electricity end-consumer agglomerates into the behaviour of the electricity market, **the aim of Paper No. 2 was to study the development scenarios of liberal electricity market under the various technological and behavioural aspects of end-consumers**.

Since the lighting sector uses up to 1/5 of total electricity worldwide and the price for light bulbs has dropped by 99.7 % in the past two centuries[6], this sector has

[4] Laicane I., Blumberga D., Blumberga A., Rosa M. (2015). Evaluation of Household Electricity Savings. Analysis of Household Electricity Demand Profile and User Activities. Energy Procedia, 72, 285–292. https://doi.org/10.1016/j.egypro.2015.06.041

[5] On average, 20 % higher electricity savings were observed in households using smart meters compared to the control group (without smart metering); these findings are above the range of previously conducted studies.

[6] Nordhaus W. D. (1996). Do Real-Output and Real-Wage Measures Capture Reality? The History of Lighting Suggests Not. In: The Economics of New Goods, 27–70.

high potential for energy savings. New lighting technologies diffuse quickly, but still around 1/3 of the households in Germany chose to replace incandescent light bulbs with the same incandescent light bulbs in 2012[7]. **Therefore, the aim of Paper No. 3 is to develop a model of innovation diffusion for energy efficiency solutions in households.** To the Thesis author's knowledge, there have been no studies connecting the aspects of innovation diffusion and personal values in one, comprehensive socio-technical model.

1.2 Eco-Innovation Diffusion

Eco-innovations are increasingly used to substitute the existing products or services; therefore, understanding the diffusion of eco-innovations is critical as some of them have reached a mature state, but the diffusion rate is slow and the path unclear[8].

Holistic theory to explain the diffusion of eco-innovations is not defined yet, and there is little known about the importance of the various factors in the diffusion process. **Therefore, the aim of Paper No. 4 is to propose a conceptual model for eco-innovation diffusion**. Unlike other theories that concentrate mainly on one set of factors, this study tries to integrate factors, as well as find the interconnectedness of multiple motivational levels. Also, the developed model can forecast the influence of policy measures.

The study on eco-innovation diffusion presented in Paper No. 4 and the study on the intention to recycle by Tonglet et al. (2004)[9] observed a similar diapason of the explained data by the model, with the highest adjusted deviance of 33.5 %. While such accuracy is regarded as a medium and acceptable result for behavioural studies[10], the author of the Thesis aims to improve these model's statistics.

Thus, the goal of Paper No. 5 is to present a conceptual methodology for a hybrid model of eco-innovation diffusion. This methodology integrates both white-box and black-box research methods to improve the model. Next, **the aim of Paper No. 6 is to test the hybrid methodology of eco-innovation diffusion for the specific case study**. As the white-box model, the system dynamics and statistical data analysis tools are used (including social psychology aspects), and as the black-box model – artificial intelligence tool is used. To the Thesis author's knowledge, this is the first attempt to model the eco-innovation diffusion process by hybrid modelling, which includes all four given methods.

[7] Mills B., Schleich J. (2014). Household transitions to energy efficient lighting. Energy Economics, 46, 151–160.

[8] Karakaya E., Hidalgo A., Nuur C. (2014). Diffusion of eco-innovations: A review. Renewable and Sustainable Energy Reviews, 33, 392–399.

[9] Tonglet M., Phillips P. S., & Bates M. P. (2004). Determining the drivers for householder pro-environmental behaviour: Waste minimisation compared to recycling. Resources, Conservation and Recycling, 42(1), 27–48.

[10] Cohen J. (1988). Statistical power analysis for the behavioral sciences, Vol. 2. Hillsdale, NJ: Lawrence Erlbaum Associates, p. 567. doi: 10.1234/12345678.

2 RESEARCH METHODOLOGY

2.1 Single Mixed Modelling Approach

In the Doctoral Thesis, the single mixed research methodology is defined as the use of a single qualitative and quantitative research method together. As a qualitative method, the survey (based on the goal-frame theory by Lindenberg & Steg (2007)[11]) of focus groups was used. As a quantitative method, the system dynamics was applied.

2.1.1 Goal Frames

Goal-frame theory explains the motivation behind the households' choice, based on three guiding goal frames: gain, normative, and hedonic. In the case of the gain goal, the households would save the electricity because it saves money. In the case of the normative goal, the savings could be explained by social pressure or environmental awareness. And, finally, the hedonic goal would be activated in the case when saving energy brings joy, for example, the commodities with higher energy efficiency are more user-friendly. To assess the presence of goal frames, the survey of a study group was conducted. Survey data were processed, and guiding goal frames were identified (see Paper No. 1). Further, these goal frames were integrated in the system dynamics model, and this model was developed in Paper No. 2.

2.1.2 System Dynamics

System dynamics was introduced by Forrester (1958)[12]. This methodology identifies the interaction between and among physical activities, information flows, and policy measures, thus revealing the dynamical nature of the variables. The main structure of the system dynamics model is described by causal loops (Fig. 3), where the causal loops define the feedback mechanisms within the system under study[13].

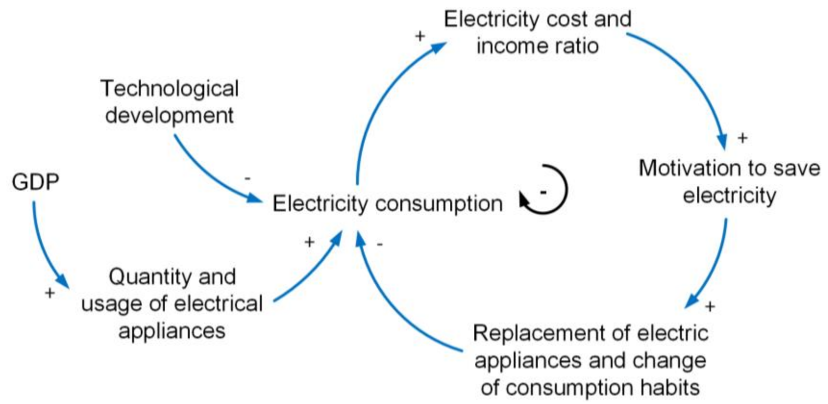

Fig. 3. The diagram of causal loops for the behaviour aspects of electricity users.

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[11] Lindenberg S., Steg L. (2007). Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social Issues, 63(1), 117–137.

[12] Forrester J. W. (1958). Industrial dynamics: a major breakthrough for decision makers. Harvard Business Review, 36(4), 37–66.

[13] Forrester J. W. (1961). Industrial Dynamics. Waltham, Pegasus Communications.

Two major causal loop diagrams were used in the system dynamics model. One of these causal loops is where an increased welfare (given as Gross Domestic Product – GDP) of a household results in the increase in the *quantity and usage of electrical appliances*, thus increasing the *electricity consumption*. On the other hand, the *technological development* of electrical appliances rises the energy efficiency, thus reducing the specific *electricity consumption*. To study the major assumptions used in the system dynamics model and for more details on the model's structure, see Paper No. 2.

2.2 Multiple Mixed Modelling Approach

In the Thesis, the multiple mixed research methodology is defined as the use of more than one qualitative and/or quantitative research method together. As the qualitative method, the survey (based on the goal-frame theory by Lindenberg & Steg (2007)[14]) of focus groups was used. As quantitative methods, statistical data analysis and system dynamics modelling were applied (see Fig. 4).

Multiple mixed modelling approaches were used in both Paper No. 3 and Paper No. 4. Both papers differ in the study fields. However, from the methodological perspective, the fundamental difference between both papers lays in the algorithm how inputs from an empirical study are assembled to fit the research question and the system dynamics model. In the case of Paper No. 4, the diffusion dynamics of one particular eco-innovation – microfibre cloth (MFC) for surface cleaning purposes – is studied, whereas Paper No. 3 studied the transition dynamics among various types of light bulbs. Therefore, in this situation, the methodology was upgraded to multinomial regression model.

2.2.1 Empirical Study

Factor analysis was performed to reduce the amount of variables used in further data analysis by extracting the optimal number of common factors from the initial variables. The model of orthogonal common factors by Johnson & Wichern (2002)[15] was used. As rotation method, the varimax rotation, $\Psi_{VARIMAX}$, was applied:

$$\Psi_{VARIMAX} = \arg\max_{R}\left(\sum_{j=1}^{k}\sum_{i=1}^{p}(\Phi\Psi)_{ij}^{4} - \frac{1}{p}\sum_{j=1}^{k}\left(\sum_{i=1}^{p}(\Phi\Psi)_{ij}^{2}\right)^{2}\right), \tag{1}$$

where Φ –s a $p \times k$ orthonormal matrix (of column eigenvectors); p – original variables; k identifies the variables; Ψ – an orthonormal rotation matrix; Ψ_{ij} – the scalar element in the i-th row and j-th column in matrix Ψ. As the measure of sampling adequacy, Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) test were done. The logistic regression analysis was performed to fit the regression model in which the dependent variable characterizes an event with only two possible outcomes: to use MFC, or not to use MFC.

[14] Lindenberg S., Steg L. (2007). Normative, gain and hedonic goal frames guiding environmental behavior. Journal of Social Issues, 63(1), 117–137.

[15] Johnson R.A., Wichern D.W. (2002). Applied Multivariate Statistical Analysis. Prentice Hall, 640. p.

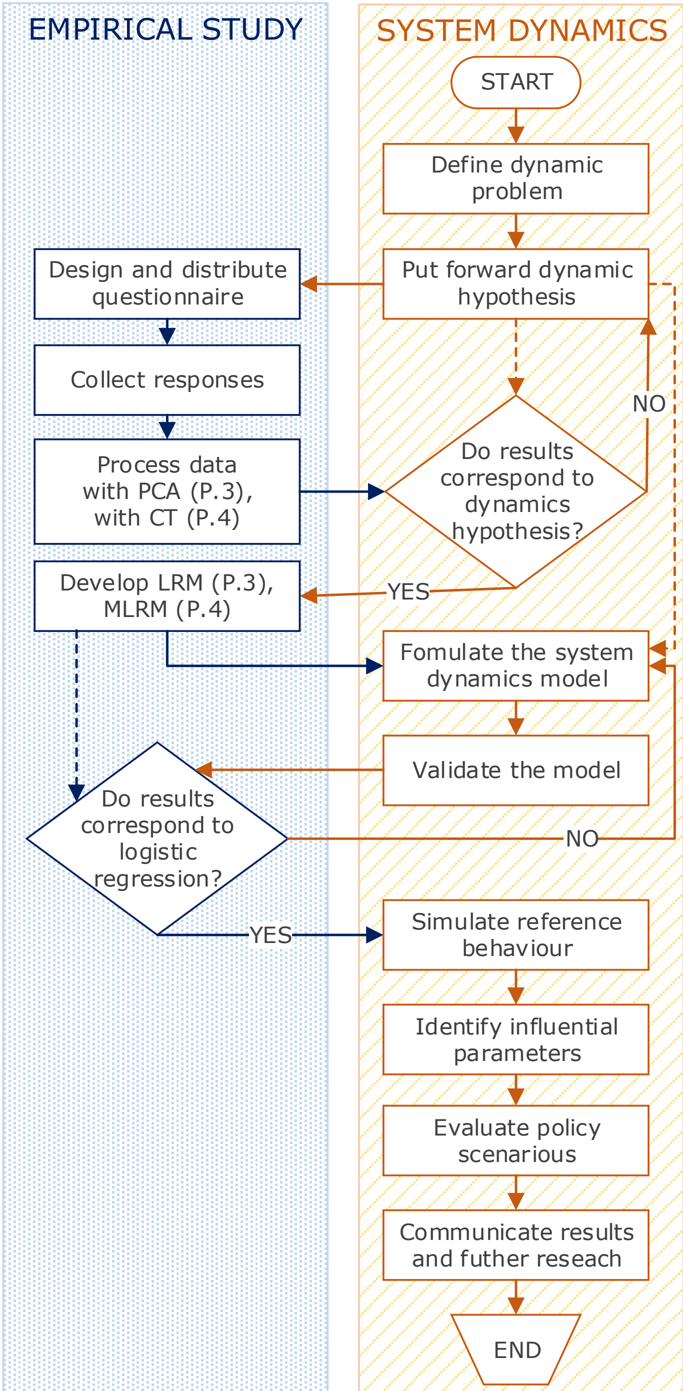

Fig. 4. Conceptual scheme of methodology used to study the transition dynamics in lighting sector (Paper No. 3) and eco-innovation diffusion dynamics (Paper No. 4) with statistical analysis tools, system dynamics and social psychology framework (PCA – principal component analysis; CT – cross-tabulation; LRM – logistic regression model; MLRM – multinomial logistic regression model; P. 3 – Paper No. 3; P. 4 – Paper No.4).

2.2.2 System Dynamics Model

The system dynamics model in Paper No. 4 converts the results obtained from the statistical data analysis into a mathematical model for the diffusion of eco-innovations to allow for the prediction of a system's behaviour over time. The accumulated avoided traditional cleaning agents are calculated as given in Eq. (2):

$$AA_{CA} = \int_{t=0}^{t=1} (C_{week} \cdot fr_{CA} \cdot HH_A) t \cdot dt + AA_{CA}^{init}, \quad (2)$$

where AA_{CA} – accumulated avoided traditional cleaning agents, tonnes; C_{week} – weekly consumption of traditional cleaning agents, tonne/household per week; fr_{CA} – fraction of traditional cleaning agents used parallel to MFC; AA_{CA}^{init} – initial value of accumulated avoided traditional cleaning agents, tonnes. A more detailed picture of the model and the major assumptions of the model are given in Paper No. 4.

2.3 Hybrid Modelling Approach

In the present Thesis, the hybrid modelling approach is referred to the use of both combined and mixed research methods. In this approach, the combined research method uses both qualitative and quantitative methods, and the mixed research method uses both white-box (system dynamics) and black-box (artificial neural network – ANN) methods.

Hybrid modelling methodology for the case study of eco-innovation diffusion was developed in Paper No. 5. As black-box modelling, ANN was used, because ANN obtains mathematical relations for relatively small, incomplete and noisy date sets[16]. Also, ANN better handles the course of dimensionality (see Fig. 5).

The ANN describes the goal framing theory by mapping the respondents answers from the survey to their behaviour. The system dynamics model is used to outline the broader effects of the consumer's behaviour, such as societal transitions and technological substitution in the society. The mathematical model of the basic artificial neural network structure is given in Eq. (3):

$$u_k = \sum_{i=1}^{n} w_{ki} x_j = w_{k1} x_1 + w_{k2} x_2 + \ldots + w_{kn} x_n, \quad (3)$$

where $x_i = (i = 1, 2, \ldots, n)$ input signals from n external neurons transmitted to the neuron k; w_{ki} weight between the i-th external input and the neuron k; u_k output from the summation function, see Figure 2.4 for graphical representation.

Pre-processing of input data was done by data splitting into three subsets: 70 % of data for the training set, 15 % of data for the validation, and 15 % of data for the test set. Data normalization between 0 and +1 was done with the logistic sigmoid transfer function, and data normalization between −1 to +1 was done with the linear or tangent transfer function. A non-linear autoregressive neural network (NARX) with an external input was chosen for training purposes of the ANN[17].

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[16] Dreyfus G. (2005). Neural Networks, Methodology and Applications. Berlin, Heidelberg: Springer Berlin Heidelberg.

[17] Fischer S., Frey P., Drück H. (2012). A comparison between state-of-the-art and neural network modelling of solar collectors. Solar Energy, 86(11), 3268–3277.

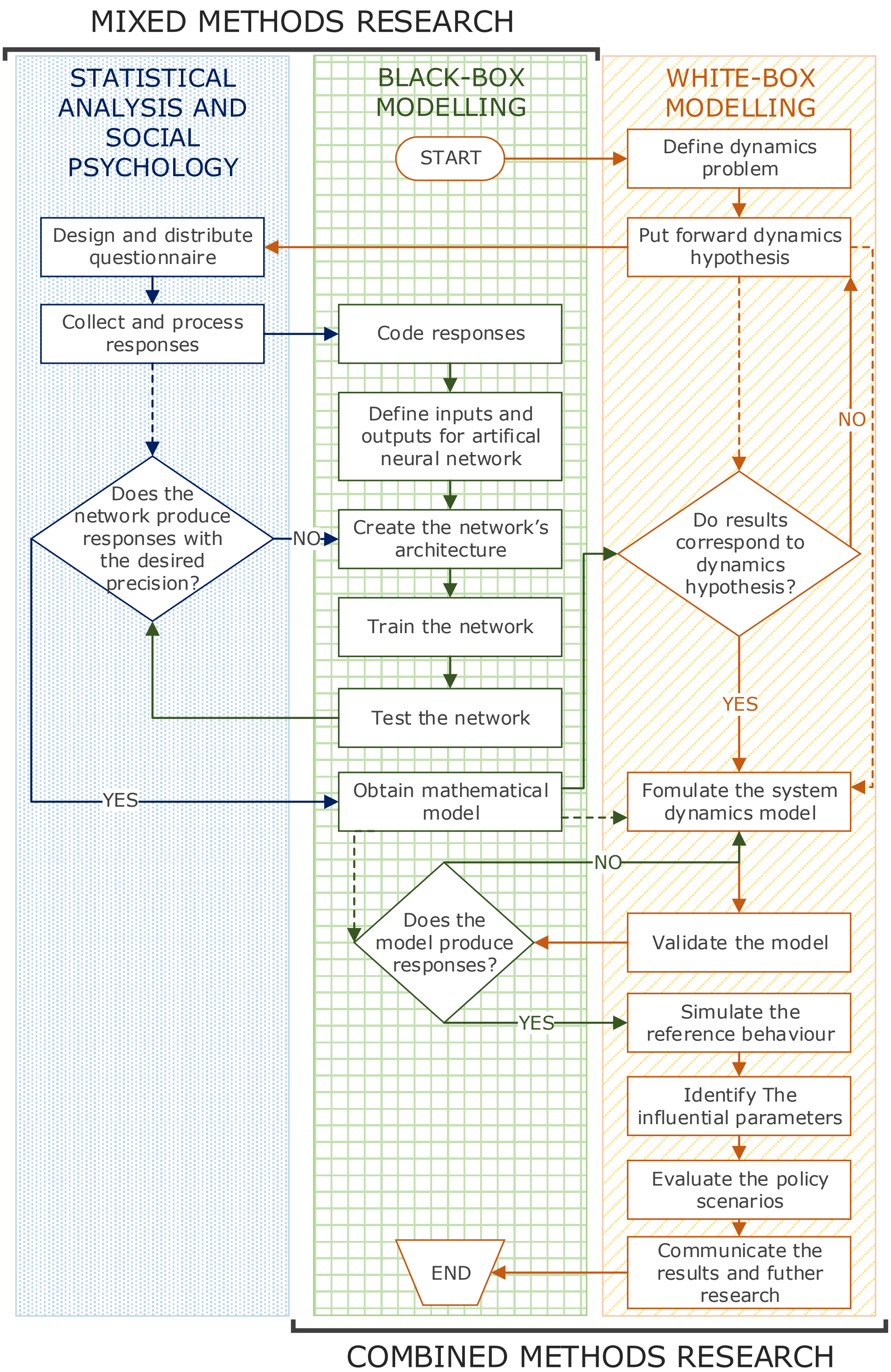

Fig. 5. The layout of the proposed hybrid methodology for socio-technical transitions.

3 RESULTS AND ANALYSIS OF THE STUDY

3.1 Single Mixed Modelling Approach

In the system dynamics model, the consumption behaviour was modelled. Three theoretical cases were created:

1) base scenario;
2) optimistic scenario, in which half of the households take part in electricity saving due to environmental concerns, and half of the households – due to gains;
3) pessimistic scenario, in which 80 % take action due to gains, but remaining 20 % take action due to environmental concerns.

The results for scenario analysis are given in Fig. 6.

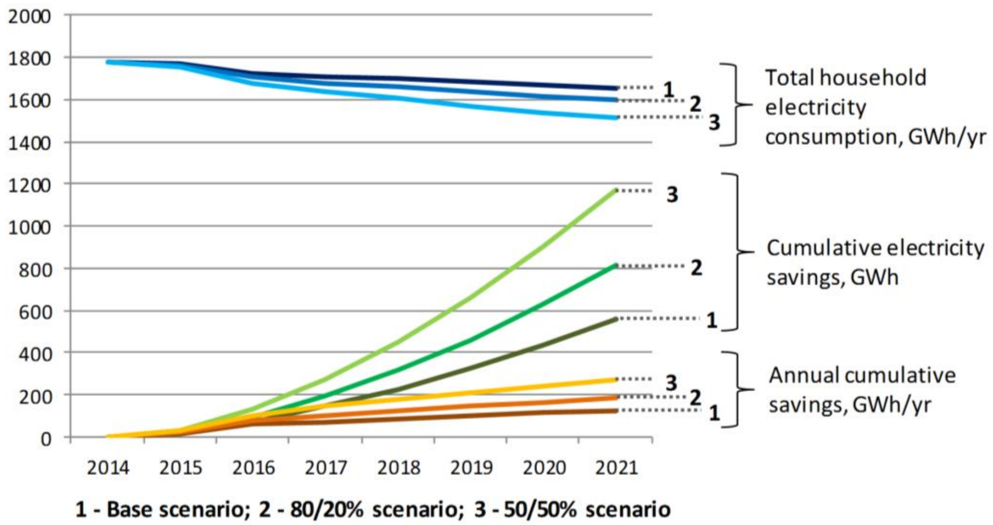

Fig. 6. Dynamics of household electricity consumption and annual cumulative electricity savings in scenario analysis using the change in consumption behaviour.

Such division of households can be supported by the study of Schwarz & Ernst (2009)[18] on the diffusion of environmental innovations in Germany. The results show that if the proportion of environmentally concerned households increases, the electricity savings become greater; see Paper No. 8 for more details.

3.2 Multiple Mixed Modelling Approach

In this section, the results of two case studies are presented: Paper No. 3 on energy efficiency and conservation, followed by Paper No. 4 on eco-innovation diffusion.

[18] Schwarz N., Ernst A. (2009). Agent-based modeling of the diffusion of environmental innovations - An empirical approach. Technol Forecast Soc, 76(4), 497–511.

3.2.1 Study on Energy Efficiency and Conservation

Firstly, the relationship between two purchases of the two types of bulbs – initial and replaced – was tested using the Chi-square test. The Chi-square test statistics showed a statistically significant pattern among the data: $\chi^2 = 89.560$, $Df = 4$, $p < 0.0001$ (see Fig. 7).

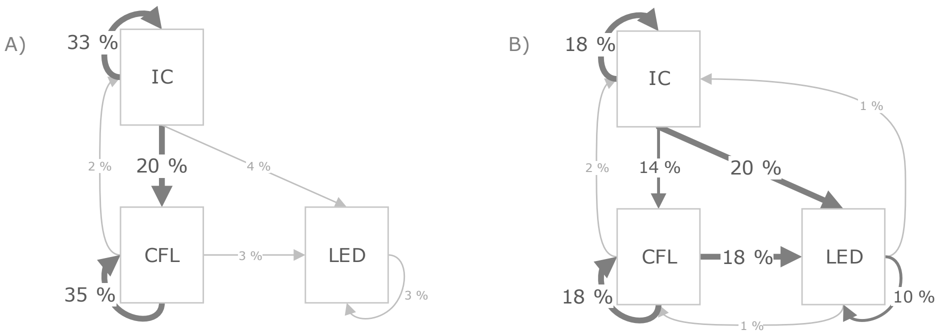

Fig. 7. The technological substitution of various light bulbs: (A) in Germany in the year 2012 ($N = 3028$), adapted from Mills and Schleich (2014)[19], and (B) in Latvia in the year 2015 ($N = 439$) (IL – incandescent light bulbs; CFL – compact fluorescent light bulbs; LED – light emitting diodes).

The sensitivity analysis for the share of IL, CFL and LED bulbs was done for both the low-income and the high-income households (see Fig. 8).

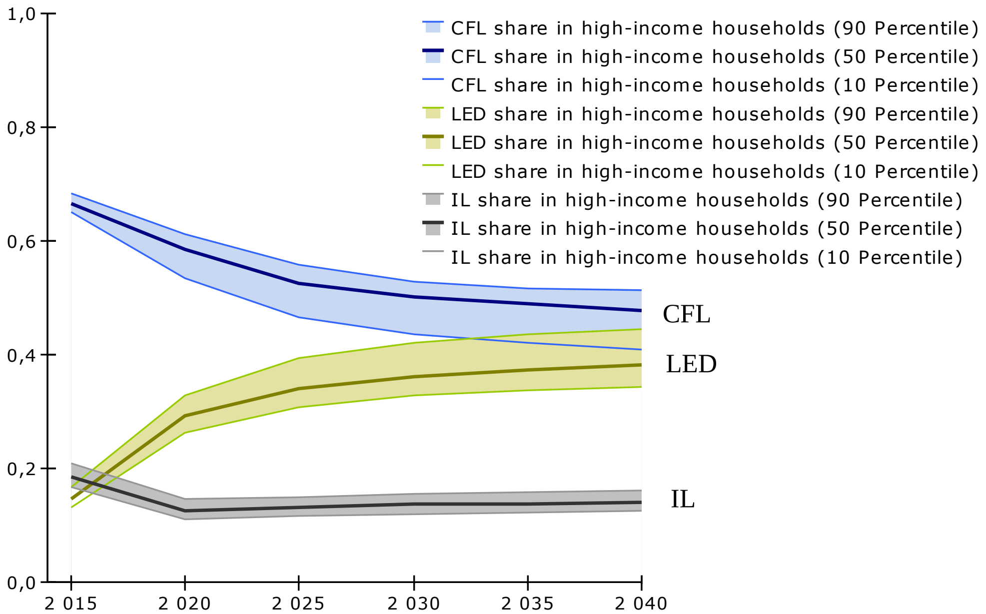

Fig. 8. Sensitivity analysis of IL, CFL and LED bulbs' share in high-income households (IL – incandescent light bulbs; CFL – compact fluorescent light bulbs; LED – light emitting diodes).

[19] Mills B., Schleich J. (2014). Household transitions to energy efficient lighting. Energy Economics, 46, 151–160.

The sensitivity analysis shows the margin of uncertainty for the share of various light bulbs by 2040: for CFL bulbs, this uncertainty is within the margin from −15 % to +6 %; for LED bulbs from −11 % to +16 %, and for IL bulbs ±14 % at the 50 percentile in high-income households. As for the same type of bulbs but in the low-income households: for CFL bulbs from –12 % to +8 %, for LED bulbs ±12 %, and for IL bulbs ±13 %.

Two main motivations – financial and environmental – were found for the use of energy-efficient lighting, which is supported by the study of Wall & Crosbie (2009)[20]. As given in the high- and low-income households, there is still some proportion of households using the incandescent light bulbs.

This phenomenon is found also in the work by Chappin & Afman (2013)[21] where they explain that some individuals look more on the costs of instant purchase but they fail to estimate the longer-term costs expressed as the expenditure for the electricity bills. Also the work by Perlaviciute & Steg (2015)[22] reveals that disregarding the commonly based assumption that economic gains are the strongest motivator, the biospheric values play an important role in the evaluation of various alternatives in the energy field.

3.2.2 Study on Eco-Innovation Diffusion

The final model "Intention to use MFC" explained 41.74 % of deviance and 34.38 % of adjusted deviance. If compared to the study by Tonglet et al. (2004)[23] where the intention to recycle was studied, the adjusted deviance in the present Doctoral Thesis is in the same range (34.38 % vs. 33.3 %) (see Table 2).

Table 2. Analysis of deviance, residuals and goodness of fit for the model "Intention to use MFC (microfibre clothes)" (N = 126)

Model	Deviance explained, %	Adjusted deviance, %	Df	MSE	Chi-square at Df = 1
Intention to use MFC	41.74****	34.38	4	$1.97 \cdot 10^{-2}$	0.87 (p >0.05)

**** Significant at $p < 0.0001$.

Since the *p* value for Chi-square test is greater than 0.05, there is no reason to reject the adequacy of the fitted model and it can be concluded that the logistic function adequately fits the observed data.

20 Wall R., Crosbie T. (2009). Potential for reducing electricity demand for lighting in households: An exploratory socio-technical study. Energy Policy, 37(3), 1021–1031.

21 Chappin E. J. L., Afman M. R. (2013). An agent-based model of transitions in consumer lighting: Policy impacts from the E.U. phase-out of incandescents. Environmental Innovation and Societal Transitions, 7, 16–36.

22 Perlaviciute G., Steg L. (2015). The influence of values on evaluations of energy alternatives. Renewable Energy, 77, 259–267.

23 Tonglet M., Phillips P. S., Bates M. P. (2004). Determining the drivers for householder pro-environmental behaviour: Waste minimisation compared to recycling. Resources, Conservation and Recycling, 42(1), 27–48.

Only information campaigns were analysed under the scenario analysis, since Steg et al. (2014)[24] state that the activities targeted to reduce the costs of some particular pro-environmental activities or to increase the costs of environmentally harmful behaviour have only a short-term effect (see Fig. 10).

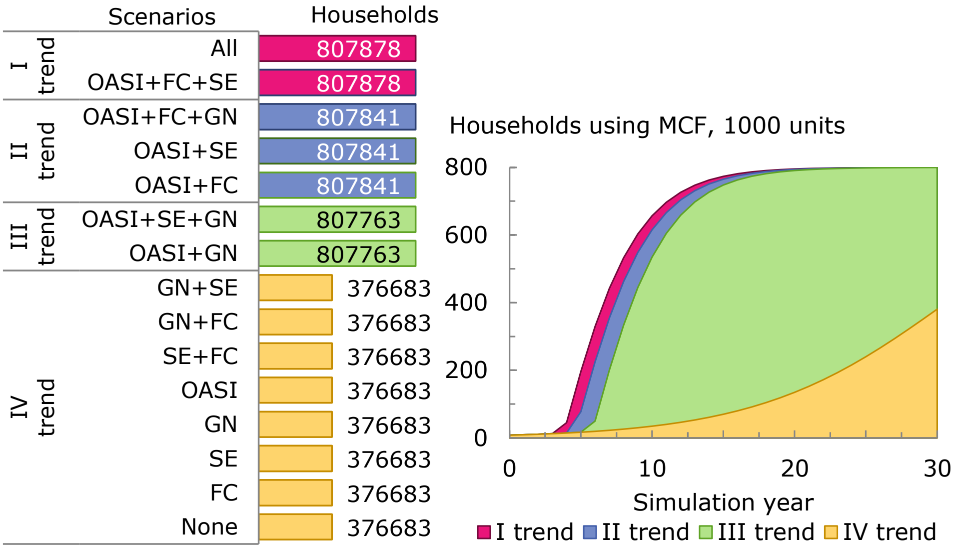

Fig. 10. The results of the scenario analysis under various information campaigns the proposed innovation diffusion model. Overall attitudes and social influence (OASI), functionality and controllability (FC), self-efficacy (SE) and green norms (GN).

This finding is directly supported by the research of Ozaki (2011)[25] where signing for "green" electricity is also strongly dictated by social pressure. These results demonstrate that social acceptance is an important source of motivation for consumer choice in Latvia. All motivations alone are found not effective, and the same conclusions have been found by Abrahamse (2005)[26] – the rewards have encouraged a change in the behaviour but only in the short term (for more details see Paper No. 4).

[24] Steg L., Bolderdijk J. W., Keizer K., Perlaviciute G. (2014). An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. J Environ Psychol, 38, 104–115.

[25] Ozaki R. (2011). Adopting sustainable innovation: What makes consumers sign up to green electricity? Bus Strateg Environ, 20(1), 1–17.

[26] Abrahamse W., Steg L., Vlek C., & Rothengatter T. (2005). A review of intervention studies aimed at household energy conservation. J Environ Psychol, 25(3), 273–291.

3.3 Hybrid Modelling Approach

The behaviour explained in various works is summarized in Table 3 using adjusted R^2. Nevertheless, these figures given are not reliable for the comparison of the model's quality, they only present the range of the behaviour explained in the models used so far.

Table 3. Behaviour explained using different methods

Study on	Adjusted R^2	Method use	Reference
Energy efficiency motivation	13 %	Statistical analysis	Bariss, Timma & Blumberga (2014)[27]
Waste recycling motivation	33 %	Statistical analysis	Tonglet et al. (2004)[23]
Innovation diffusion model	34 %	Statistical analysis & system dynamics, & social psychology	Paper No. 4
Upgraded innovation diffusion model	89 %	Hybrid modelling approach	Paper No. 6

As given in Table 3, a total of 89 % of the behaviour is explained in the case when ANN is used together with the white-box modelling methodologies and social psychology. While the ANN describes the goal framing theory by mapping the respondents' answers, the system dynamics model is used to outline the broader effects of the consumer's behaviour, such as societal transitions and technological substitution in the society.

[27] Bariss U., Timma L., Blumberga D. (2014). Smart metering pilot project results. Energy Procedia, 61, 2176–2179.

CONCLUSIONS

In this Thesis work, a novel modelling methodology is developed. The presented methodology combines the aspects of technical and social systems and natural environment, thus providing holistic methodology tools to study socio-technical transitions. Socio-technical transition processes are studied from the perspective of various sectors, such as energy use, production and management, innovation diffusion, and others. The transitions are studied from the lenses of various possible methods and their combinations.

As to the Thesis author's knowledge, this is the first time that socio-technical transitions have been studied by using the latest knowledge and advanced modelling tools for the engineering and social science field together. Also the methodology that uses both white-box models (system dynamics) in combination with black-box models (artificial intelligence) has been developed and validated in the Thesis.

The presented methods allowed guiding the decision making process and modelling the outcomes of various development scenarios. By applying obtained knowledge, the sectors were targeted to reach a sustainable development goal more effectively. The presented Doctoral Thesis allows transferring the developed methodology to study other technologies and services at different levels of the economy.

Single Mixed Modelling Approach on Energy Efficiency and Conservation

The framework is presented to model household's behaviour and electricity savings in a holistic and dynamic way. The social aspects of the consumer behaviour for higher energy savings are integrated. With the help of this model, not only the retrospective situations could be analysed but also the future savings of policy could be assessed.

For the simulation of electricity market liberalization, system dynamics has been chosen. This method can determine electricity savings, since system dynamics allows conducting the simulation of complex systems and analysing the obtained data to forecast the probability of the development of several scenarios. The obtained results show that cumulative electricity savings in households could reach 560 GWh by the end of 2020 because of the opening of electricity market. In the case of scenario analysis using the change of consumption behaviour, it was obtained that the cumulative electricity saving could be almost twice as big if the majority of households would be guided by the environmental concerns.

Multiple Mixed Modelling Approach

a) On Energy Efficiency and Conservation

The methodology was developed and validated using an empirical study (social psychology with statistical data analysis) together with system dynamics modelling. The adoption intention of energy-efficient lighting solutions in Latvia is used as the case study.

Two main motivations – financial and environmental – were found for the use of energy-efficient lighting. Therefore, policy makers should consider that both in high and low income households, incandescent light bulbs are still in use, since some individuals look more on the costs of an instant purchase but they fail to estimate the longer-term costs expressed as the expenditure for the electricity bills.

Long-term policy should not only take into account the economic side of the bulb purchase but start on putting more and more emphasis on the personal values of consumers. The results reveal that disregarding the common assumption, economic gains are not the strongest motivator, but biospheric values play an important role in the evaluation of alternatives in the energy field.

Although the system dynamics model was based on the specific innovation diffusion process, its general application to other products and services is possible since the developed model is a white-box model.

b) On Eco-Innovation Diffusion

The goal of this research was to develop a conceptual model for eco-innovation diffusion based on consumer choice. This study sheds light on the explanation of pro-environmental behaviour. The diffusion of microfibre clothes (MFC) in Latvia for cleaning purposes in households was selected as a case study.

The proposed conceptual model studies the influence of information campaigns to reinforce the adoption of the studied eco-innovation products. Novel methodology has been developed under the system dynamics framework and was coupled with the logistic regression model. The model allows for the outlining of the dynamics under technological substitution within the context of the eco-innovations' diffusion. Structural validation tests were done for the proposed model.

The proposed methodology and developed conceptual system dynamics model can also be used as the basis for other studies of various diffusion processes, since system dynamics modelling is a white-box modelling approach, and the structure of the model can be enhanced with the latest results from other studies.

Hybrid modelling approach on Eco-Innovation Diffusion

The hybrid modelling approach for eco-innovation diffusion is presented. This methodology combines both mixed and combined research methods to improve the validity and reliability of study results. As a quantitative method, the survey of focus groups is used; as qualitative methods, the artificial neural networks, statistical data analysis and system dynamics are applied. All these four methods (quantitative and qualitative) together present the hybrid modelling approach.

With this work, the contribution to the applications of hybrid research methods in the field of eco-innovation diffusion and environmental studies is done. The obtained results show that the model can explain 89 % of the systems behaviour. The application of the presented methodology can be extended for various socio-technical problems. Although the model was based on one specific technological substitution process, its general application to other products and services is possible since the developed model is fully outlined and can be used for further research of other processes.