EMI R&D PROJECT PROGRESS REPORT

Reporting year

2026

Project Title:

Enviro-PEEX(Next) on ECMWF: Research and development for seamless modelling of meteorology – atmospheric composition on multi-scales for the Pan-Eurasian EXperiment (PEEX) domain for weather, air quality and climate applications

Computer Project Account:

SPFIMAHU-2025

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Start date of the project:

March 2025

Expected end date:

December 2027

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		2025		2026	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(SBU)	400,000	33,093	400,000	8,020
Data storage capacity	(Gbytes)	4,000		4,000	

Summary of project objectives (10 lines max)

The main objectives of the Enviro-PEEX(Next) on ECMWF Special Project are to analyse the importance of the meteorology-chemistry-aerosols interactions and feedbacks and to provide a way for development of efficient techniques for on-line coupling of numerical weather prediction and atmospheric chemical transport via process-oriented parameterizations and feedback algorithms, which will improve the numerical weather prediction, climate and atmospheric composition forecasting.
The main application areas to be considered include improving: (i) numerical weather prediction with short-term feedbacks of aerosols and chemistry on meteorological variables; (ii) atmospheric composition forecasting with two-way feedbacks between aerosols/chemistry and meteorology; (iii) coupling of aerosols and chemistry aiming towards better description of aerosols and relevant microphysical processes, and their effect on radiative fluxes and clouds; and (iv) understanding and ability in prediction of chemical and physical processes related to the formation and growth of atmospheric particles.

Summary of problems encountered (10 lines max)

There are no problems encountered.

Summary of plans for the continuation of the project (10 lines max)

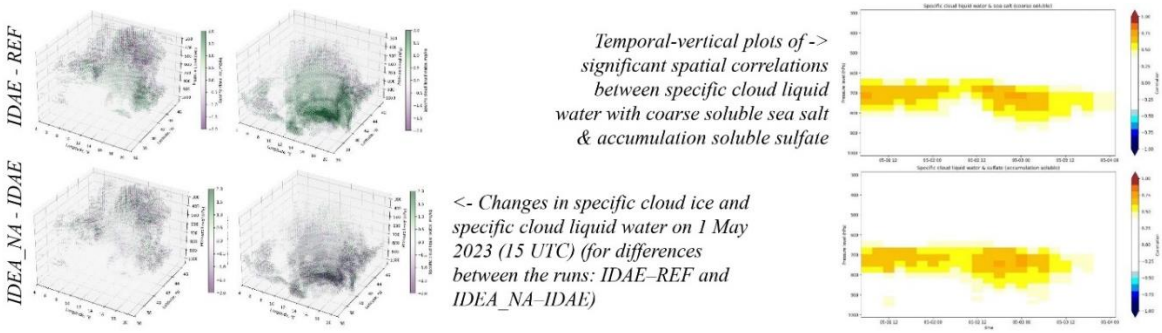
The workplan outlined in the proposal will be continued according to the planned activities. These developments towards the PEEX-Modelling-Platform will provide additional scientific value for the numerical weather prediction, atmospheric composition forecasting, and climate modelling communities. In particular, simulations are expected for: (i) short-term case studies with physical and chemical weather downscaling forecasting to evaluate sensitivity of aerosol effects on meteorology, atmospheric composition and climate; (ii) episodes for weather, climate and air quality applications to evaluate possible effects; (iii) testing parameterisations, meteorological and chemical initial and boundary conditions, and chemical data assimilation.

Summary of results

1. Implementation Concept: "The Pan-Eurasian Experiment Modelling Platform (PEEX-MP)"
The PEEX-MP is one of key blocks of the PEEX Research Infrastructure. It includes more than 30 different models. The approach has focus on a concept of seamless/online integrated environmental prediction, which allows to better understand physical-chemical-biological processes, Earth's system interactions and feedbacks, and to provide valuable information for assessment studies for population, environment and climate in the PEEX geographical domain. The PEEX-MP presents a strategy for best use of current generation modelling tools to improve process understanding and improve predictability on different scales in the PEEX domain. The seamless coupling includes different processes, components, scales and tools. The scales to be considered cover scales from micro- to local, urban, sub-regional, regional, hemispheric, global; and from box-model to large eddy simulations, meso- and climate scales. The horizontal resolutions for modelling are ranging from a few meters to more than a degree in the latitudinal-longitudinal domain. The processes, at the current moment studied at different degree of understanding and to be considered include meteorological and climatological, chemical and aerosols, biological, hydrological, and others as well as considering society interactions. Available observations for atmosphere and ecosystems (in particular, from the SMEAR-type stations and PEEX meta database stations) are to be used for data assimilation and data processing as well as for the models' validation and verification studies. In particular, the Enviro-HIRAM modelling system continues further development and application (*Mahura et al., 2025*) for different research tasks according to the PEEX Science Plan (PEEX-2015; https://www.atm.helsinki.fi/peex/images/PEEX_Science_Plan.pdf).

2. Study: "Studying indirect aerosol effects during heavy rain episodes in midlatitude deep cyclone synoptic conditions"
Savenets et al. (2025), Hrama et al (2026), utilising seamless modelling approach and considering uncertainties in modelling aerosol-cloud-meteorology interactions, is focused on analysis of different aerosol impacts on

extreme weather events, cases with convective clouds and anthropogenic impact land use/land cover changes with enhancing consequences. Heavy rain episodes in the midlatitudes turn often into hazardous natural disasters, causing flooding events, infrastructure damage, and environmental repercussions. The aerosol–meteorology feedbacks sometimes remain uncertain despite their tremendous role in such episodes. The study is conducted to identify key aerosol–cloud interactions during two heavy rain episodes that occurred in Europe in 2023: one over the Italy region in May 2023 and another over the Black Sea – Ukraine region in Nov 2023. Utilizing ECWMF and CAMS initial and boundary conditions for meteorology and atmospheric composition, observational data, emissions, the simulations were performed over the geographical domains of southern Europe (with focus on Italy) and eastern Europe (with focus on Ukraine). Simulations – Enviro-HIRLAM runs as reference (REF) without any effects, indirect aerosol effects included (IDAE), IDAE but without anthropogenic emissions – were performed in a downscaling chain at resolutions of 15, 5, 2+ km resolutions.

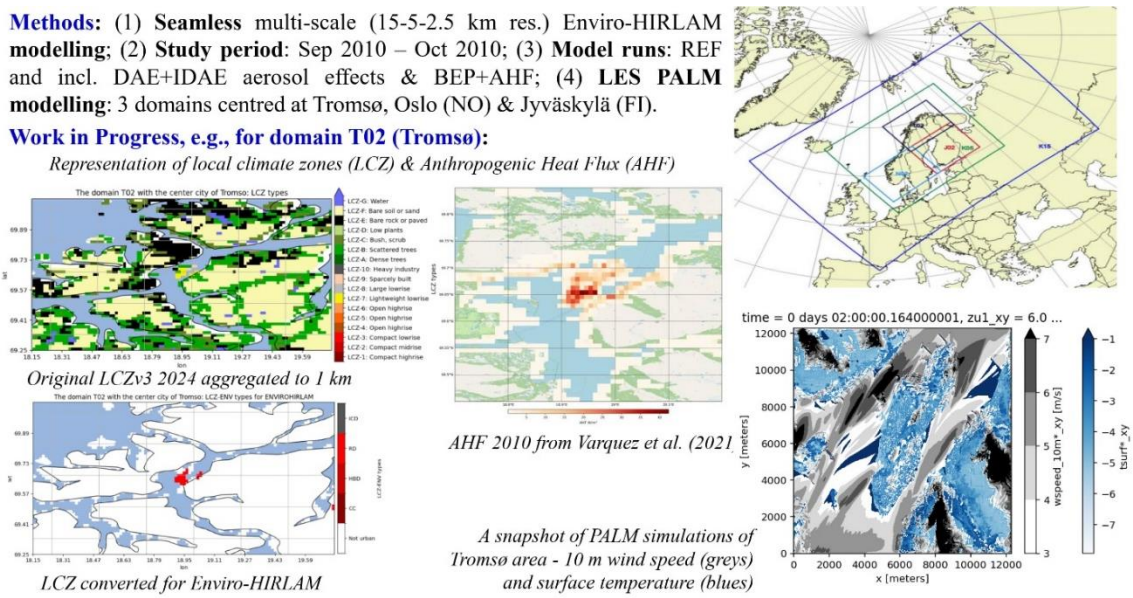


Examples of Enviro-HIRLAM model output for 1 May 2023 (15 UTC) for runs/ configurations and differences.

Preliminary results showed that during heavy rain associated with midlatitude deep cyclone synoptic conditions, increased concentrations of sulfate and sea salt aerosols led to a significant enhancement of specific cloud ice, liquid water, cloud condensate, and cloudiness in the 2–4 km layer. Opposite effects were observed at higher altitudes. In the boundary layer, the consequent changes included a prevailing decrease in air temperature. However, despite the increases in these parameters, no significant enhancement of total precipitation was observed. This suggests that complex atmospheric feedbacks govern precipitation formation, and that increased cloud water content does not necessarily translate into increased surface rainfall. *Manuscript is in preparation.*

3. Study: "Integrated urban environmental modeling: from development to implementation"

Esau et al. (2025) aims at combined examination of urban climate and atmospheric pollution through an integrated methodology employing high-resolution numerical modelling and data fusion techniques. The proposed approach seamlessly merges urban scale large-eddy simulations, performed at a meter-scale using PALM model, with a kilometer-scale meteorological simulations using the Enviro-HIRLAM model. The project will ensure comprehensive understanding of urban environmental dynamics.



Processing urban related characteristics on example of Tromso, Norway; Enviro-HIRLAM for regional, subregional, and 3 urban geographical domains; example of PALM model output.

In this study the simulations are performed in the downscaling chain with resolutions of 15, 5 and 2+ km resolutions (at regional, subregional, and urban scales). The runs are performed for Sep-Oct 2010 with configurations shown in Figure 2. At the urban scale, data from the existing local climate zones (LCZs) from the World Urban Database and Access Portal Tools (WUDAPT) for high-latitude cities and towns were extracted and integrated into the model domains for cities of Oslo, Tromso, and Jyvaskyla. At this scale the building effects parameterization (BEP) and anthropogenic heat fluxes (AHF) were also implemented in the model and activated for each grid cell containing urban fraction. The LCZs data could be used not only for thermal climate characterization but also more holistically for description of urban atmospheric dynamics and vertical mixing, and therefore urban air pollution dispersion. *Manuscript is in preparation*

4. Study: "Investigating urban heat island and their impacts on air pollution over Copenhagen metropolitan area"

Sahyoun et al (2025) focused on enhancing the understanding of the interactions among urban multimodal mobility, traffic emissions, air quality, and thus, climate change in cities. The Enviro-HIRLAM is utilized for multi-scenarios simulations, and for proposing multi-mode transport schemes conducive to sustainable development, with emissions reduction and mitigation of health and climate risks. The urban morphology and anthropogenic heat flux (AHF) are implemented into the model to study urban heat island (UHI) events and air quality in the Copenhagen metropolitan area of Denmark, and to evaluate how these factors influence 2-m air temperature and particulate matter (PM2.5) levels and validate against high-resolution reanalysis and observational data.

Methods: (1) **Seamless** multi-scale (15-5-1.5 km res.) Enviro-HIRLAM **modelling**; (2) Implementation of updated **urban classification** (Local Climate Zones, LCZs; WUDAPT); (3) **Study period**: 1-7 Sep 2010; (4) **Model runs**: Urban Off vs. Urban On for AHF0 and AHF23; (5) **Reanalysis data**: DANRA; (6) **In-situ obs.** (DMI)

LCZs & Observation sites

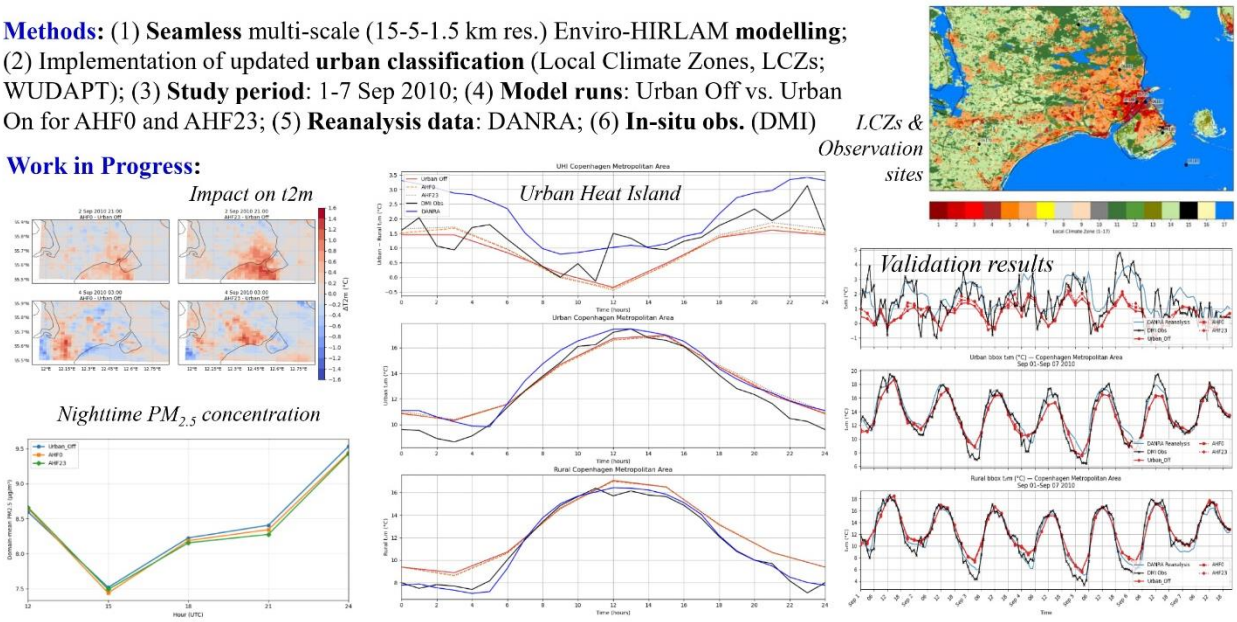
Work in Progress:

Impact on t2m

Urban Heat Island

Validation results

Nighttime $PM_{2.5}$ concentration



Examples of Enviro-HIRLAM model outputs; diurnal cycle for UHI characteristics for different model runs/configurations; Copenhagen metropolitan area classification based on LCZs; and validation results.

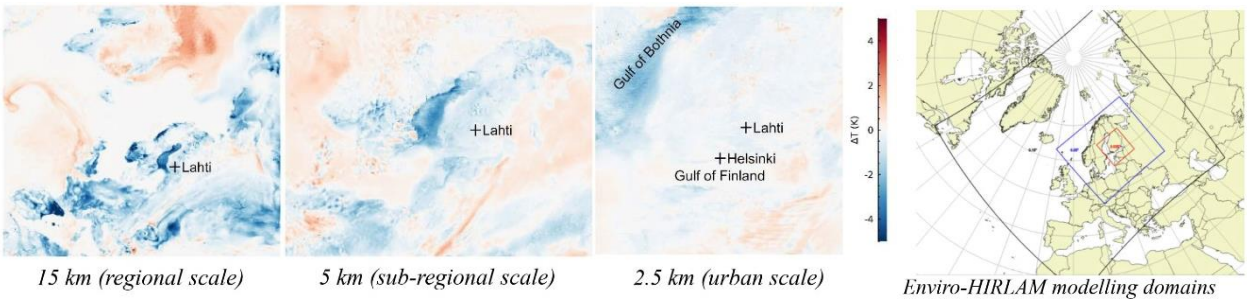
The preliminary results showed that incorporating urban morphological characteristics and canopy processes significantly improves the representation of UHI intensity and spatiotemporal variability over Copenhagen. Sensitivity analyses further highlight the influence of AHF and LCZ-specific characteristics on model performance. This study underscores the importance of integrating the accurate urban characteristics into urban climate modelling to enhance predictive capability and support urban climate adaptation strategies. *Manuscript is in preparation*.

5. Study: "Impacts of ecological restoration on air quality and local meteorology in Lahti"

This study, focused on air quality and local meteorology, aims to quantify and evaluate local, regional and remote long-range sources of air pollution for city of Lahti (Finland) employing the Enviro-HIRLAM and FLEXPART-SOSAA modelling systems, to evaluate on how future scenarios (e.g., emission reduction, regional afforestation, and urban greenery restoration) will impact air quality and local-scale meteorology.

The study is focused on seamless simulations of the impact of two ecological restoration scenarios on air quality and meteorological conditions (e.g., urban heat island effect) for this city, with focus on the aerosols feedback effects on meteorology. The modelling is performed at multi-scales from regional-subregional-to-urban (at 15-5-2.5+ km resolutions) for a period from Dec 2022 to Sep 2023. Then, the trajectory, atmospheric chemistry, and aerosol dynamics modelling was performed with employing the FLEXPART-SOSAA and

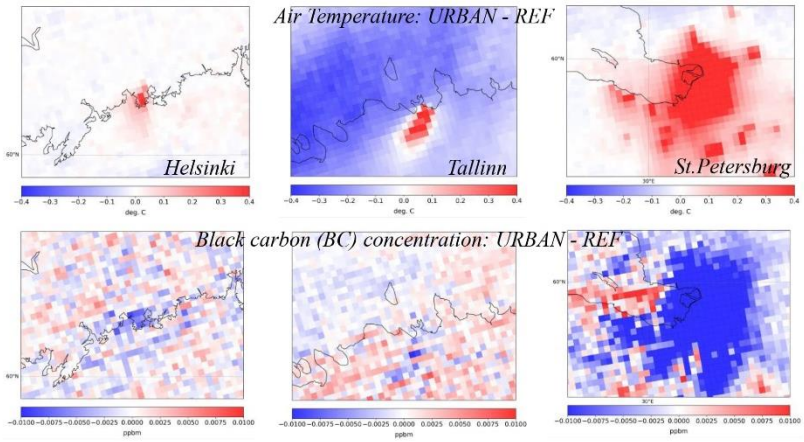
utilising the Enviro-HIRLAM output. The scenarios considered are the restoration of urban loans into natural meadows through reduced mowing and the regional forest restoration in southern Finland. The focus is on growing period (Spring - early Autumn), and empirical data are from the Carbon-Conscious Greenspaces study, and air quality measurements in Lahti. *Manuscript is in preparation*.



Examples of Enviro-HIRLAM model run/output in downscaling chain (15, 5, 2.5+ km resolutions) on 15 Mar 2023, 12 UTC, showing aerosol feedback effects on surface temperature; geographical model domains.

6. Study: "Seamless modelling of atmospheric state and composition under influence of cities in the Baltic Sea region"

This study aims to carry out evaluation of interaction between the atmospheric boundary layer and metropolitan areas. For that the Enviro-HIRLAM model with building effect parametrization module and anthropogenic heat flux is employed to simulate meteorology and atmospheric composition (with focus on aerosols) for urban areas (Helsinki, Tallinn, St. Petersburg) in the Baltic Sea region. The simulations (at 5 and 2.5+ km resolutions) are performed on a subregional scale and then on urban scale for the period from 16 March until 4 May 2023 with focus in analysis on April 2023. The model at urban resolution is run in several configurations – REF (reference run), URB (run with implemented building effects parameterization (BEP) module and anthropogenic heat fluxes (AHF), and URBAER (URB + both direct and indirect aerosol effects included).
Preliminary results showed that urbanized runs provide higher near the surface air temperature and lower near surface black carbon concentrations in the Baltic cities. *Manuscript is in preparation*.



Examples of Enviro-HIRLAM model output (for air temperatures and black carbon concentration) with focus on urban effects influence.

7. Study: "Assessment of the current state of atmospheric air in the Atyrau region (Republic of Kazakhstan) in the sustainable development context"

The study is aimed to carry out a comprehensive research of the air basin quality in the Atyrau region (Republic of Kazakhstan) using meteorological and air quality monitoring data related, to simulate meteorology and atmospheric composition (with focus on aerosols) on regional scale with Enviro-HIRLAM, and to develop a set of recommendations for improving air quality management on a basis of scenario assessments and advance diagnostics of air environment parameters.
Utilising ECWMF and CAMS initial and boundary conditions for meteorology and atmospheric composition, observational data, emissions, the simulations were performed over the geographical domains of the western Republic of Kazakhstan with focus on the Atyrau region at 5 km resolution for periods of Jan-Feb 2023 and Jun-Jul 2023 as for the cold and warm periods in Kazakhstan. Meteorological data from 9 meteorological stations and atmospheric pollution data from 6 air quality posts to be used for the model validation.

8. Science Education with Enviro-HIRLAM model at Young Scientists School (YSS)

(1) The hybrid YSSchool on "*Climate Change and Related Risks*" is held at Fudan University, China during 6-24 Jul 2026, and it is focused on climate change, cities and anthropogenic impacts. Four main lecturing modules are focused on the climate change and urban climate effects, extreme weather events and their impacts, atmospheric environment and eco-health impacts, and AI-enabled sustainable development and climate resilience. The YSS will include also group/team work on practical exercises as small-scale research projects (SSRPs), and for the Enviro-HIRLAM model the SSRP is focused on evaluating the urban effects on meteorology.

(2) YSSs on "*Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications*" have been included in 2 proposals (with COST Action, funded by EU and with TFK programme funded by Finland). In all these events, the lecturing on seamless modelling, and Enviro-HIRLAM SSRPs with focus on analysis of aerosol effects (direct, indirect, combined) on meteorology at regional-subregional-urbans scales – are included.

List of publications/reports from the project with complete references

Mahura A., R. Nuterman, A. Baklanov, M. Savenets, L. Pysarenko, I. Esau, B. Foreback, G. Nerobelov, M. Sahyoun, F.D. Avdi, G. Musralinova, S. Polyakova, M. Boy, R. Makkonen, T. Petäjä, H.K. Lappalainen, M. Kulmala (**2025**): Enviro-HIRLAM Research, Development, and Application. *pp. 172-173 In the REPORT SERIES IN AEROSOL SCIENCE, No.304; Abstract Book of the ACCC-FASN Science Conference 2025 (10-12 Nov 2025, Helsinki, Finland), Eds. (Li, Wang, Kinnunen, Andaz, Ovaska); ISBN 978-952-7507-83-4*

Hrama, D., Pysarenko, L., Nadtochii, L., Rudas, M., Savenets, M., Mahura, A., and Petäjä, T. (**2026**): Enviro-HIRLAM model simulations of aerosol–cloud interactions during two cases of heavy rain in Italy and Ukraine, *EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-520, doi.org/10.5194/egusphere-egu26-520, 2026.*

Savenets M., L. Pysarenko, A. Mahura, T. Petäjä, M. Kulmala (**2025**): Studying indirect aerosol effects during heavy rain episodes in midlatitude deep cyclone synoptic conditions. *pp.264-265 In the REPORT SERIES IN AEROSOL SCIENCE, No.304; Abstract Book of the ACCC-FASN Science Conference 2025 (10-12 Nov 2025, Helsinki, Finland), Eds. (Li, Wang, Kinnunen, Andaz, Ovaska); ISBN 978-952-7507-83-4*

Esau I., V. Miles, A. Mahura, A. Baklanov (**2025**): Application of the local climate zone (lcz) concept in multi-scale model studies of urban micro-climates. *pp. 45-46 In the REPORT SERIES IN AEROSOL SCIENCE, No.304; Abstract Book of the ACCC-FASN Science Conference 2025 (10-12 Nov 2025, Helsinki, Finland), Eds. (Li, Wang, Kinnunen, Andaz, Ovaska); ISBN 978-952-7507-83-4*

Sahyoun M., F. D. Avdi, M. M. Knudson, R. Nuterman, A. Mahura, H. J. D. Sørup, J.H. Christensen, A. Baklanov (**2025**): Urban heat island investigation over Copenhagen metropolitan area with Enviro-HIRLAM. *pp. 259-260 In the REPORT SERIES IN AEROSOL SCIENCE, No.304; Abstract Book of the ACCC-FASN Science Conference 2025 (10-12 Nov 2025, Helsinki, Finland), Eds. (Li, Wang, Kinnunen, Andaz, Ovaska); ISBN 978-952-7507-83-4*

PEEX (**2015**): Pan-Eurasian Experiment, PEEX Science Plan. Eds. H.K. Lappalainen, M. Kulmala, S. Zilitinkevich. ISBN 978-951-51-0587-5, ISBN 978-951-51-0588-2 (on-line), 307p, www.atm.helsinki.fi/peex/images/PEEX_SP__27052015.pdf