Final report

RE:think

Rethink and improve product design and service cost for circular economy business models

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RE:
SOURCE

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Final report for the project:

RE:think

Engelsk titel: Rethink and improve product design and service cost for circular economy business models

Projektperiod: 2022-08-15 - 2025-08-14

Datum: 2025-09-30

Projektnummer: P2022-00342

Diarienummer: 2022-200510

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Nyckelord: 5–7 st: Product-as-a-service, circular economy, business model, product development, service cost.

RE:Source är ett strategiskt innovationsprogram och finansieras av

VINNOVA Energimyndigheten FORMAS

Contents

1. Sammanfattning

RE:think-projektet syftade till att stödja den svenska tillverkningssektorn i att hantera den angelägna samhällsutmaningen med resursuttömning och uppnå förbättrad ekonomisk prestanda genom utveckling av Product-as-a-Service (PaaS). Specifikt erbjöd projektet stöd till företag för att navigera i komplexiteten kring att designa resurseffektiva PaaS-lösningar, med praktiska och direkt tillämpbara metoder för att effektivt utforma sådana lösningar. Två svenska tillverkningsföretag med olika karaktär – Toyota Material Handling (TMH) och QleanAir – har aktivt deltagit i projektet och bidragit till utvecklingen av breda insikter och metoder. Specifikt har allmänt tillämpliga utmaningar och möjligheter för PaaS-design identifierats. Två direkt tillämpbara metoder för att stödja olika aspekter av design och implementering av PaaS har utvecklats. Dessa resultat har visat sig vara användbara för de två partnerföretagen samt för andra externa företag, vilket tyder på en stor potential för bred tillämpning.

2. Summary

The RE:think project aimed to support the Swedish manufacturing sector to address the pressing societal issue of resource depletion and achieve enhanced economic performance through Product-as-a-service (PaaS) development. Specifically, this project offered support for companies to navigate the complexities of designing resource-efficient PaaS solutions with practical and readily applicable solutions to effectively design PaaS solutions. Two Swedish manufacturing companies, with different characteristics, Toyota Material Handling (TMH) and QleanAir, have actively participated in this project and contributed to the development of widely applicable findings and methods. Specifically, widely applicable challenges and opportunities for PaaS design have been found. Two readily applicable methods to support different aspects of PaaS design and deployment have been developed. These outcomes have been found to be useful by the two partner companies and other external companies, pointing towards the potential for widespread applicability.

3. Introduction and background

PaaS is believed to be a prerequisite to tackle the resource challenge while simultaneously enhancing economic performance in the Swedish manufacturing industry (Tukker, 2015).

However, research suggests that for product developers the process of designing PaaS is significantly different and more complex than that of designing typical product centric solutions, due to uncertainty emerging from the PaaS lifecycle such as product use, deterioration and services among other sources (Neramballi et al., 2025). Furthermore, a transition toward a PaaS based business model significantly affects the perceived value and the cost structure for both customers and providers, which needs to be balanced. However, achieving this balance has been found to be challenging as such a transition often leads to higher costs for the provider, which is subsequently passed on to the customers (Vogt Duberg & Sakao, 2024). Thus, exploiting the full potential of PaaS in industrial practice has been found to be challenging due to the high complexity of designing and developing such solutions.

Therefore, the goal of this project was to create practical models on the technology readiness level (TRL) six that Swedish OEMs can exploit for improving their product designs and service operations under PaaS offerings: one reference model for product development adapted to PaaS aiming to increase the efficiency and one mathematical model calculating service costs for minimization. The lifecycle perspective has been adopted to guide the model development for environmental sustainability. The impacts are lead time reduction for developing resource-efficient PaaS offerings with improved economic performance. TMH and QleanAir are the industry partners of this project. Use cases and the related data were provided by the two partner companies and other external companies. The companies collaborated closely with researchers from Linköping University (LiU) to co-create the knowledge. Both industry partners offered different perspectives on resource-efficient PaaS development. Specifically, TMH is a large multi-national corporation (MNC) with a significant global footprint while QleanAir is a small/medium sized enterprise (SME), with operations primarily based in Sweden and Europe. TMH offers forklifts (see the left of the exhibition below) and warehouse logistics solutions, while QleanAir provides air ventilation (e.g., smoking cabins and air purifiers - see the right of the exhibition below) based PaaS solutions. While TMH has been providing both PaaS based offerings and product sales offering, QleanAir has been offering PaaS solutions since its conception.

Exhibition 1. Exteriors of example products of the two industry partners (left: TMH, right: QleanAir. Source: the companies)

4. Implementation

4.1. WP1: Project management and dissemination

One of the industry partners that was commited to the project and core part of the application encountered internal issues within their organization after the project approval and eventually dropped out from the project despite the contact person's willingness to collaborate within this project. The project leader approached multiple companies to find a new partner, and the RE:Source program (Jan Agri) also helped the process. Thereby, QleanAir joined this project. This process took time and caused a delay of WP2, while LiU worked for WP3 using the data from a company outside the current consortium from Month 1. On November 8, 2023, LiU held a physical meeting for a full day with TMH and QleanAir (13 participants in total) at LiU. Research and management matters were discussed to further plan the project activities. Furthermore, LiU held another on-site full-day consortium meeting with TMH and QleanAir (9 participants in total) at TMH Innovation Centre, Linköping, in May 2025. In this meeting, the final results of the project were discussed and applied together with the industry partners. On 12th June, 2025, a research webinar was carried out by the RE:think researchers to disseminate the project results to the Swedish manufacturing industry. Further, two popular science articles and two conference papers were published, and two scientific articles were prepared for publication (see the full list in Section 7). One policy brief was prepared and is under review.

4.2. WP2: Innovate product development procedures for PaaS

This work package aimed to develop a reference model for the product development procedures of Swedish OEMs, adapted to the PaaS context to increase resource efficiency and financial performance from the lifecycle perspective.

Initially, an in-depth gap analysis was carried out partly by engineers and engineering managers at TMH and QleanAir in collaboration with LiU researchers. Subsequently, existing practices in the product and PaaS development of the participating companies were compared with insights from the state-of-the-art. The primary focus for TMH in this project was narrowed down as supporting the achievement of high-level netzero or resource efficiency targets by identifying challenges and making suitable changes in the design process. To address this focus, two workshops were carried out in Fall 2024 with TMH, followed by interviews with key personnel in Winter 2025 and an internal dissemination workshop in Spring 2025.

Since QleanAir is a fully fledged PaaS offering company, their focus areas were narrowed down to identifying suitable key performance indicators (KPIs) in the state-of-the-art that are relevant to PaaS design practices, environmental impacts, and communication, e.g., product reuse ratio, part reuse ration, etc. and finding opportunities to improve their design process. Furthermore, QleanAir expressed an interest in exploring opportunities for optimizing their service routes and design. Three on-site and four online workshops were carried out with QleanAir to address the identified focus areas.

In total, six in-person and four online workshops were held for the project. Furthermore, this work package aimed to co-develop fitting solutions for the challenges that the partners' current models cannot meet and to generalize the insights toward a broadly applicable reference model. As a spin-off, interest for collaboration has been expressed from outside the project in further validating the KPIs for PaaS solutions and in the development of a policy brief for facilitating the development of resource-efficient PaaS solutions.

4.3. WP3: Innovate service cost estimation for PaaS

This work package aimed to develop an innovative approach for companies to effectively carry out service cost estimation for PaaS solutions. More specifically, this work package aimed to develop a method that enables Swedish OEMs to calculate and minimize economic costs of services in their envisioned PaaS offerings, using existing product/part failure data from practice. The focus of the model was to address the challenge of datasets, which include potentially heterogenous customer groups with different usage patterns. Furthermore, distinguishing service policies can be applied to dedicated groups. In a conventional manufacturing system without PaaS, a single service policy is often applied to all customer groups, ending with either too early or too late service, and thereby risks of failure and higher costs. Therefore, this work

package aimed to develop an analytical model and a method that can help companies identify when maintenance of products across different customer groups with different usage patterns can be carried out as cost effectively as possible. To validate this model, data of two different customer groups with different usage patterns of 10 different products were collected from a construction machine manufacturer (an external partner). Subsequently, the developed method and the model were introduced to the partner companies in two physical workshops, and opportunities to develop similar models with their datasets were explored.

4.4. WP4: Synthesize outcomes and generalize results

This work package aimed to synthesize the outcomes of WP1-WP3 co-developed with the partner companies and to generalize the findings in terms of broadly applicable results or methods. Since the two companies have significantly different characteristics and maturity levels of their PaaS business model, the synthesis of the outcomes provided a unique opportunity to generalize the findings that are broadly applicable to a wide range of companies. The synthesis results have been described in an accessible form for the Swedish industry. Thus, the developed knowledge is expected to support the Swedish industry to better adapt their product development procedures to PaaS offerings with improved environmental and economic performance.

5. Results and discussion

5.1. WP1: Project management and dissemination

For dissemination of project activities, the project leader applied for inclusion in IVA's 100 list in 2023, which is organized by the Royal Swedish Academy of Engineering Sciences (iva.se) to promote businesses' interests in research projects in Sweden. As a result, this project has been nominated coupled with its sister project Scandere (EU co-funded ERA-MIN3 program): https://www.iva.se/en/what-iva-does/awards/ivas-100-lista-eng/products-and-services-for-product-as-a-service/

Royal Swedish Academy of Engineering Sciences

Our research is included in **IVA's 100-list 2023** listing research projects focusing on **climate change**, **energy supply**, **welfare technology**, **cyber security** and **crisis preparedness**. Deemed to have great potential to benefit through commercialization, business and method development or societal impact.

Tomohiko Sakao was invited for many events. First, he was a panelist with three other industry practitioners for ESG- och Hållbarhetsdagen 2023 by PwC in Stockholm on November 15: https://www.pwc.se/esg-och-hallbarhetsdagen The panel focused on circular business models, including PaaS, by building upon a whitepaper on PaaS for the electronics sector, including lifecycle costing (PwC, 2023). The recorded session is published: https://www.youtube.com/watch?v=otGvNC9tyDQ See a snapshot below.

Second, he was a panelist in a Euroconsumers webinar "Renting consumer "products as a service": costly gimmick or green dream? in 2024. Third, he presented a keynote paper on circular economy implementation in 2024 at CIRP General Assembly.

Fourth, he was invited for a plenary keynote presentation on circular economy at REMADE Circular Economy Tech Sumit & Conference, Washington DC in 2024. See a snapshot below.

Tomohiko Sakao and other members of Linköping University were engaged in the following activities and thereby disseminated the knoelwdge. First, in working groups for ISO TC323 on Circular Economy, which published standards in 2024. Second, in ISO/CEN meeting in Brussels on developments in CEN Circular Economy standards. Third, in Almedalen Week partly as invitation by Delegationen för Cirkulär Ekonomi.

The empirical findings of this research project have been disseminated to the two industry partners through multiple on-site and online workshops and to the Swedish manufacturing industry through a webinar and two popular science articles (one policy brief under review). Furthermore, two scientific articles were prepared for peer-reviewed outlets.

5.2. WP2: Innovate product development procedures for PaaS

The workshops and interviews with TMH revealed several challenges in adapting the design processes for achieving high level resource efficiency goals across the following focus areas: information transfer and requirements management (e.g. transferring environmental requirements to those with agency), data handling and the issue of data heterogeneity (e.g. lifecycle costing not in focus and crucial data stored in silos), communication and collaboration (e.g. lack of homogenous communication with upstream actors), and the balancing sustainability initiatives and profitability (e.g. changes in culture, high tension between sustainability goals and profitability). Specifically, designers were sometimes unaware of the environmental requirements placed on they work, and project managers and R&D managers found it challenging to implement environment-centric goals alongside economic and technological ones. The dominance of cost-centric goals over other considerations was also pointed out as a roadblock to comprehensive, lifecycle-focused product-service design. The level of collaboration required to achieve a comprehensive mindset shift toward modularization was also found to be a critical hindrance. In this context, it was confirmed that variety induced complexity is a

significant challenge that needs to be addressed to effectively ensure the development of resource-efficient and economically viable PaaS solutions. A need for a shift from mass customization to resource efficient customization was deemed necessary. To do so, the following initiatives were discussed: PaaS based modularization, measuring and analyzing the adverse effects of variety, ensuring co-ordinated collection of lifecycle data and translation of such effects of variety in terms of monetary value (Matschewsky et al., 2025).

The workshops and interviews with QleanAir revealed the need to identify best practices for PaaS designing and comparing those with their status quo. Subsequently, based on the advances in the state-of-the art such as the PaaS maturity model (Pigosso & McAloone, 2016) and the PaaS design schema (Sakao & Neramballi, 2020), potential improvements in their current product development process and service operations were identified. Examples of such improvements include ensuring management commitment and support for resource-efficient PaaS design, evaluating lifecycle environmental performance of PaaS solutions, identifying customer and stakeholder requirements to facilitate resource efficiency and increased customer interactions. Furthermore, KPIs for measuring resource efficiency were identified and discussed, based on the advances in the state-of-the-art (e.g. based on (Neramballi et al., 2020; Rossi et al., 2020)). Specifically, indicators relevant to resource-efficiency of PaaS solutions such as reused and recycled content of inflows, lifetime ratio of product or material against industrial average, ratio of critical raw material, health monitoring with digital technologies, service frequency, labour intensity and responsiveness, product disassemble-ability etc were deemed relevant for implementation within their product development process and service operations, by QleanAir. Opportunities for service route optimization were briefly discussed for instance through predictive maintenance and circular PaaS based failure mode effects analysis (FMEA) (e.g. (Kimita et al., 2021)).

Although the two industry partners are in different stages of PaaS maturity levels, both were found to lack dedicated PaaS specific design processes. To support both industry partners and similar companies undergoing transformation toward PaaS practices, a broadly applicable reference model has been developed. Empirical research reveals that while addessing PaaS design problems, product developers tend to focus primarily on product elements, while affording less effort on service elements, sub-system and product-service interactions, which are deemed to be ineffective for resource-efficient PaaS designing (Neramballi et al., 2022, 2025). It is vital to be aware of and cater to such product-service and subsystems interactions during PaaS design to avoid the risk of falling into the service design trap (Sakao, Neramballi, & Matschewsky, 2022). The service design trap is a commonly observed phenomenon in industry in which the freedom to effectively design and carry out service activities is restricted during the use phase due to frozen product designs which have not considered the interdependencies of services and vice versa (ibid). Thus, to support typical product developers to effectively design resource-efficient PaaS solutions, a dedicated method to identify and integrate latent product-

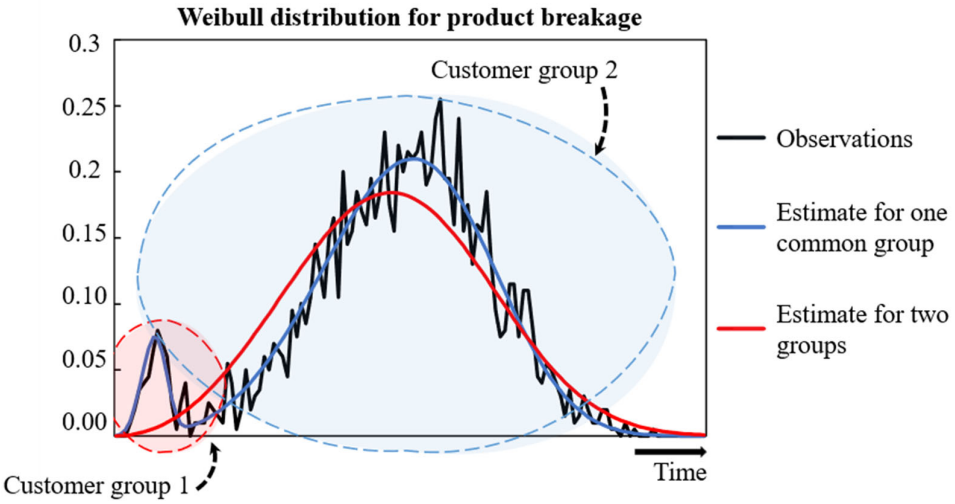
service interdependencies was developed in this project. This method builds upon the previously developed approach of systemic lifecycle engineering and product-service interdependency knowledge base (Sakao, Neramballi, Matschewsky, et al., 2022).

The knowledge base builds upon several empirical cases of product and service interdependencies and guides designers to first identify such interdependencies in their own PaaS design case and then to integrate them by using the knowledge base for inspiration. Specifically, it includes a product-service interdependency matrix, which has abstracted and condensed multiple observed cases from industry, in terms of interpendencies between generalized product and service design parameter (DP) classes. Product DP classes include Serviceability, Affordability, Information transferability, Upgradeability and Temporal functionality. Service DP classes include Labour intensity, Capability, Responsiveness, Information transferability, Affordability, Frequency and Reliability. This knowledge base was extended in this project by first adding detailed product and service DP instances to the DP classes, which are directly relevant to resource efficiency (e.g. Serviceability (Product DP class) – Product repairability (Product DP instance relevant to resource efficiency)). Second, this adapted matrix only shows the interdependencies which when integrated leads to the enhancement of resource efficiency of the overall PaaS solution. This method was introduced to the partner companies in the final onsite consortium meeting held on May 6th, during which the key personel of the two companies received the opportunity to test and apply the method within the context of their own solution development process. It was deemed to be a viable solution for initiating changes to their product development process toward resource-efficient PaaS development. A scientific journal article covering this line of research is currently under development.

5.3. WP3: Innovate service cost estimation for PaaS

As planned (Section 4.3), a mathematical model for service cost estimation has been developed in this workpackage. The developed model has been verified with the input as generated Weibull data to compare the service costs between a single vs. a dual maintenance policy. See visualization below. The output is the service costs associated with estimated distribution parameters, as well as the services policies. An initial test of this developed model demonstrated that a single policy could increase costs 1.8 times higher than a dual policy. The initial results were published and presented in the 27th International Conference on Production Research, in July 2023 (see Section 7). Further test of this model with real data from industry (the external company providing construction machinery equipment) has been carried out for the validation. The results of the validation show around 50% cost saving potential when two different customer groups are identified, as the maintenance scheduled for each product can then be optimally designed. The reliability of the method is higher, when data availability is good. The implication is that: A fact-based, real-time, automated estimation of service costs has been

shown to be feasible. The study has been summarized and submitted to International Journal of Production Research, and currently the manuscript is under revision.



5.4. WP4: Synthesize outcomes and generalize results

The outcomes of WP2 and WP3 provide a roadmap for the Swedish manufacturing industry to transform their design practices to effectively develop resource-efficient PaaS solutions and practical solutions with high TRL to overcome specific challenges faced during such a transformation. Specifically, WP2 laid the groundwork to begin such a transformation by first shining light on potential challenges faced by the partner companies and by providing guidelines for their top management to establish the necessary preconditions on the strategic and operational levels to overcome the challenges. Subsequently, approaches to align the product development and service operations of the companies toward the best practices of resource-efficient PaaS development have been outlined using the latest advances in the state-of-the-art. Furthermore, relevant KPIs to measure and control the resource efficiency of PaaS activities have also been identified. These outcomes were synthesized, communicated to and discussed with both the partner companies in an on-site workshop. These workpackages have also developed, applied and validated concrete and widely applicable methods to solve two specific PaaS design related challenges.

First, the adapted product-service interdependency knowledge base provided a practical procedure and support for designers to enhance the system resource efficiency through targeted product-service integration. Next, the service cost estimation method provided an effective solution to develop cost-efficient maintenance schedules. Since the two partner companies are of distinct characteristics and PaaS maturity levels, the knowledge developed in these two work packages are expected to have a high degree of generalizability. Furthermore, the two methods developed have both been introduced to the two partner companies in on-

site workshops and were found to be useful and potentially applicable within their own design processes. Thus, the overall findings of these work packages have a high potential for generalizability and widespread application within the Swedish manufacturing industry.

To promote the accessibility of these findings to the manufacturing industry and three popular science articles have been published. One of the popular science articles documents the research undertaken in RE:think in WP2 and other related work of the researchers of this project (Neramballi & Sakao, 2025). This report synthesizes insights into the cognitive challenges faced by product designers while designing PaaS (Neramballi et al., 2025), relevant design support that can be used to address these cognitive challenges and outlines the future research directions into an in-depth exploration of the neuro-cognitive characteristics of PaaS designing. Furthermore, the popular science article also introduces a prospective policy framework to support the design of PaaS solutions in the product manufacturing industry by overcoming systemic challenges (Neramballi et al., 2024). Two other popular science articles cover the outcomes of WP3, one in Swedish (Vogt Duberg & Tang, 2025a) and the other in English (Vogt Duberg & Tang, 2025b). Both introduce and describe the service cost estimation model, developed in WP3, in an accessible format for the manufacturing industry.

6. Conclusions, utilization, and next steps

The RE:think project has laid the groundwork to support the Swedish manufacturing industry to adapt their design processes toward the effective development of resource-efficient PaaS solutions. By collaborating with two different types of Swedish companies of different sizes, offerings and PaaS maturity levels, the project has uncovered strategic and operational challenges that may hinder resource-efficient PaaS development. Subsequently, in collaboration with the two partner companies, opportunities and solutions to overcome such challenges were identified. Best practices for PaaS design and KPIs to control resource-efficiency of PaaS have been identified and contextualized with the case companies. In line with the aims of this project, two widely applicable methods with high TRL have been developed and introduced to support resource-efficient PaaS design and deployment. Specifically, they support product-service integration and service cost estimation and service planning. To promote enhanced utilization of the outcomes of this project, two popular science articles have been published. A webinar to disseminate the findings of this project for the Swedish manufacturing industry has been carried out.

Consumer interests in PaaS exist, as indicated by the Euroconsumer webinar (mentioned in Section 5.1). It means a potential is found in consumer markets as well as business martkes. To realize this potential, several concrete avenues for future research are found.

First, it is sensible to further increase the TRLs of relevant elements of a PaaS system in focus. Here, it should be emphasized what is lacking in a society for a circular economy is implementation of a whole system and technologies for the system are often available and feasible for implementation. The necessary knowledge is so-called science of systems for circularity, which is in its infancy and needs to be further developed. Second, in relation to the system, public policies need to be further investigated as many of them have been designed for a linear economy and some of them hinder PaaS implementation. Third, it is necessary to develop knowledge on how to make PaaS a mainstream from a niche. Fourth, the knowledge related and cognitive needs of practitioners to effectively design PaaS solutions needs to be further investigated: specifically, efforts to carry out such research has begun and explained in one of the popular science articles (Neramballi & Sakao, 2025).

7. Publikationslist

Doctoral thesis

J. Vogt Duberg: Remanufacturing Initiation for Original Equipment Manufacturers, 2024, Doctoral thesis, Linköping University, Department of Management and Engineering, Environmental Technology and Management. https://doi.org/10.3384/9789180756280

Peer-reviewed articles in scientific journals

O. Tang, J. Vogt Duberg: Data analytics for maintenance with segmented customers in Product-as-a-Service environment, 2025, submitted to International Journal of Production Research, 1st revision

> Since maintenance decisions rely essentially on product's failure time affected by usage patterns, differentiating maintenance could potentially reduce failures and maintenance costs, but meanwhile it requires methods for identifying customer groups in mixed product failure datasets. Therefore, this study proposes a model and an algorithm to derive parameters from examine high order moments in a mixed Weibull distribution, thereby exploring the underlying customer groups. The advantage of distinguishing the mixed customer groups will be obvious when no single group dominates, or the failure rate is increasing and has a large value, or down time cost is significant. Using real data in a case company, we identify products with such a potential. In addition, when bimodality coefficient is medium or high, and when the ratio of two scale factors is high, there is a tendency of two modes in the distribution and distinguishing customer groups becomes essential. Our proposed model and algorithm help to realise such conditions by observing data and its moments. The study

results provide guidelines for improving maintenance performance in a product-as-a-service environment.

A. Neramballi, T. Sakao, A. Carlson, J. Matschewsky, F. Mathieux, M. Orefice: Modular lifecycle design of integrated product-service systems to address different technical lifetimes of product components for resource efficiency, to be revised and submitted to a journal.

Scientific conference contributions

J. Vogt Duberg, O. Tang: Leveraging customer usage data for optimal maintenance policies in product-as-a-service. 27th International Conference on Production Research, Cluj-Napoca, Romania, 23-28 July 2023. https://icpr2023.org/

Failure data given from practice is often unsuitable for service cost estimation in PaaS and incomplete. E.g., according to practitioners in industry that we work with, multiple user groups and multiple parts are mixed in one dataset. This paper proposed how to identify customer usage behaviour groups in a mixed product failure dataset. The method proposed and developed was an algorithmic model using the Weibull moments to distinguish the underlying Weibull distributions in a mixed dataset.

T. Sakao, S. Akkala: Social sustainability of a home appliance product-as-a-service for a circular economy. 2025 REMADE Circular Economy Tech Sumit & Conference 2025, Washington DC, April, 2025. Open access publication is being prepared by the conference organizer.

In helping industries with PaaS in the CE context by adapting their decision-making processes, design for a CE plays a central role in the conceptualization of a CE by Webster (2015). It is sensible to assume trade-offs exist between various dimensions. Addressing trade-offs and even finding a possible solution that breaks the trade-off relation is expected in designing. PSS design has a high potential to contribute to helping industries in this regard.

Articles in popular science

J. Vogt Duberg, O. Tang: Realising competitive PaaS through analysis of usage patterns across multiple customer groups, 2025, LiU-IEI-R No. 357, ISSN 2004-8602 (printed report), ISSN 2004-8610 (online), DOI: https://doi.org/10.3384/IEI-R.357

J. Vogt Duberg, O. Tang: Realisering av konkurrenskraftig PaaS genom analys av användarmönster hos flera kundgrupper, 2025, LiU-IEI-R No. 358, ISSN 2004-8602 (printed report), ISSN 2004-8610 (online), DOI: https://doi.org/10.3384/IEI-R.358 (the Swedish translation from above)

A. Neramballi, T. Sakao: From Product to Product-as-a-Service Designing: Challenges and Opportunities, 2025, LiU-IEI-R No. 356, ISSN 2004-8602 (printed report), ISSN 2004-8610 (online), DOI: https://10.3384/IEI-R.256

> This popular science articles describes the complexities faced during and opportunities available for effectively designing resource-efficient PaaS solutions for the product manufacturing industry. The range of topics includes insights into cognitive challenges faced by product designers during PaaS designing and corresponding solutions, systemic challenges for product manufacturers to effectively design PaaS and a prospective policy framework to overcome such challenges.

8. Projektkommunikation

For communication and dissemination of project results and activities, a LinkedIn page has been created and updated with news https://www.linkedin.com/company/93225846/ This page complements that made by the program: https://resource-sip.se/projekt/rethink-rethink-and-improve-product-design-and-service-cost-for-circular-economy-business-models/?en

9. Referenser

PwC, 2023. Future Proofing the Electronics Industry: The case for circular business models, Stockholm, 2023. https://www.pwc.se/sv/esg/cirkular-elektronik.html

Kimita, K., Brambila-Macias, S. A., Tillman, A., & Sakao, T. (2021). Failure analysis method for enhancing circularity through systems perspective. *Journal of Industrial Ecology*, *25*(3), 544–562. https://doi.org/10.1111/jiec.13069

Matschewsky, J., Kambanou, M. L., & Sakao, T. (2025). From mass customization to circular customization – measuring and managing variety in product service systems. *Resources, Conservation and Recycling*, *219*, 108261. https://doi.org/10.1016/j.resconrec.2025.108261

Neramballi, A., Milios, L., Sakao, T., & Matschewsky, J. (2024). Toward a policy landscape to support the product-as-a-service design process for a circular economy. *Journal of*

Industrial Ecology. https://doi.org/10.1111/jiec.13535

Neramballi, A., & Sakao, T. (2025). *From Product to Product-as-a-Service Designing: Challenges and Opportunities* (LIU-IEI-R, Vol. 356). Linköping University Electronic Press. https://doi.org/10.3384/IEI-R.256

Neramballi, A., Sakao, T., & Gero, J. S. (2022). How Do Designers Think in Systems? – Empirical Insights from Protocol Studies of Experienced Practitioners Designing Product-Service Systems. In J. S. Gero (Ed.), *Design Computing and Cognition'20* (pp. 455–472). Springer International Publishing. https://doi.org/10.1007/978-3-030-90625-2_27

Neramballi, A., Sakao, T., & Gero, J. S. (2025). Is product-service system designing different from product designing? A cognitive study of experienced product designers. *Design Science*, *11*, e8. https://doi.org/10.1017/dsj.2025.4

Neramballi, A., Sakao, T., Willskytt, S., & Tillman, A.-M. (2020). A design navigator to guide the transition towards environmentally benign product/service systems based on LCA results. *Journal of Cleaner Production*, *277*, 124074. https://doi.org/10.1016/j.jclepro.2020.124074

Pigosso, D. C. A., & McAloone, T. C. (2016). Maturity-based approach for the development of environmentally sustainable product/service-systems. *CIRP Journal of Manufacturing Science and Technology*, *15*, 33–41. https://doi.org/10.1016/j.cirpj.2016.04.003

Rossi, E., Bertassini, A. C., Ferreira, C. dos S., Neves do Amaral, W. A., & Ometto, A. R. (2020). Circular economy indicators for organizations considering sustainability and business models: Plastic, textile and electro-electronic cases. *Journal of Cleaner Production*, *247*, 119137. https://doi.org/10.1016/j.jclepro.2019.119137

Sakao, T., & Neramballi, A. (2020). A product/service system design schema: Application to big data analytics. *Sustainability (Switzerland)*, *12*(8). https://doi.org/10.3390/SU12083484

Sakao, T., Neramballi, A., & Matschewsky, J. (2022). Avoid Service Design Trap by Guiding Product/Service System Design with Product-Service Dependency Knowledge Base. *Proceedings of the Design Society*, *2*, 1955–1964. https://doi.org/10.1017/pds.2022.198

Sakao, T., Neramballi, A., Matschewsky, J., Carlson, A., Bäck, M., & Tirumalasetty, V. T. (2022). Systemic improvement of lifecycle performance by leveraging product and service interdependencies – A case of a product for wind power generation systems. *CIRP Annals*. https://doi.org/10.1016/J.CIRP.2022.04.052

Tukker, A. (2015). Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production*, *97*, 76–91. https://doi.org/10.1016/j.jclepro.2013.11.049

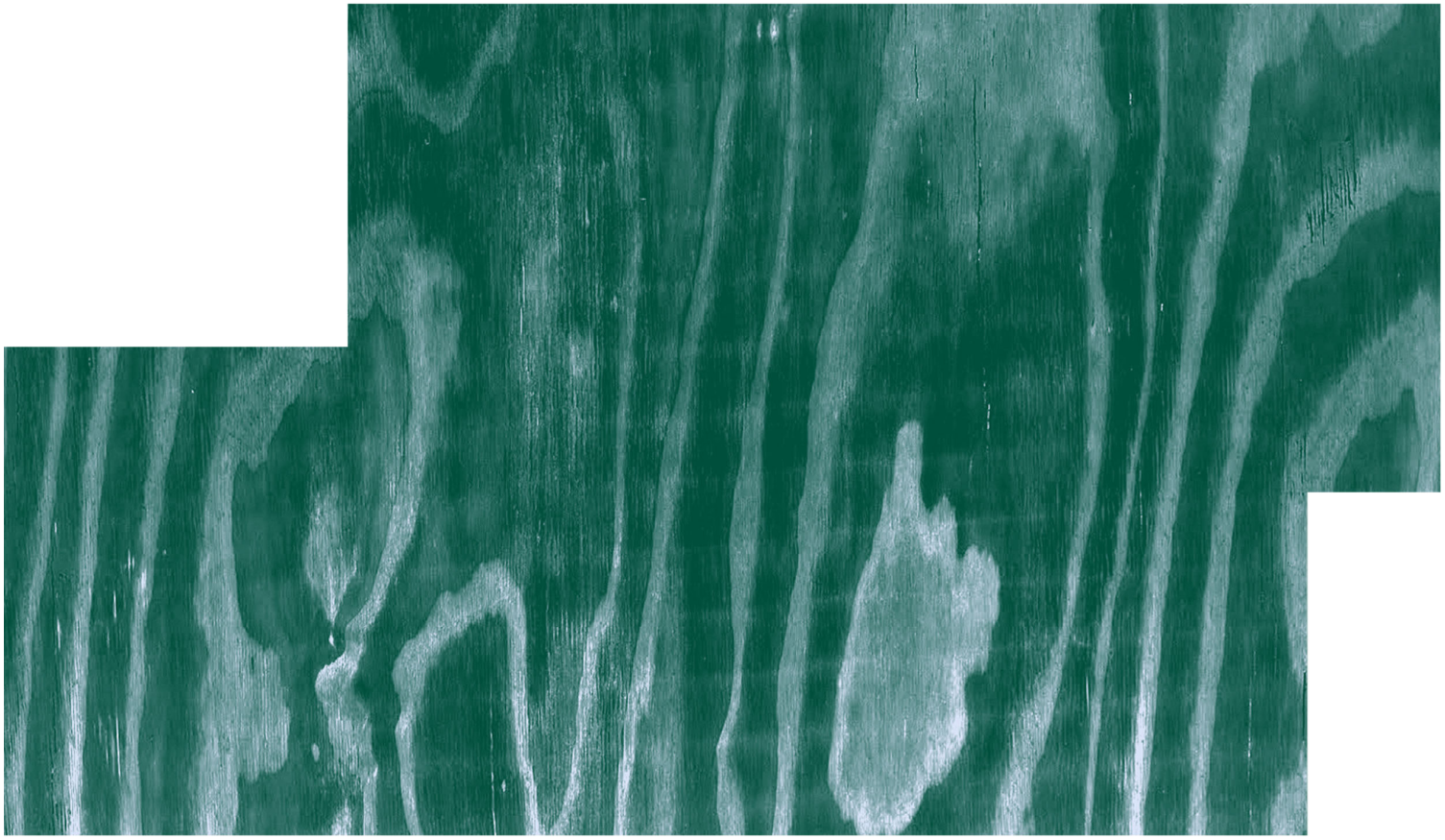
Vogt Duberg, J., & Sakao, T. (2024). How can manufacturers identify the conditions for financially viable product-as-a-service? *Frontiers in Manufacturing Technology*, *4*. https://doi.org/10.3389/fmtec.2024.1498189

Vogt Duberg, J., & Tang, O. (2025a). *Realisering av konkurrenskraftig PaaS genom analys av användarmönster hos flera kundgrupper* (LIU-IEI-R, Vol. 358). Linköping University Electronic Press. https://doi.org/10.3384/IEI-R.358

Vogt Duberg, J., & Tang, O. (2025b). *Realising competitive PaaS through analysis of usage patterns across multiple customer groups* (LIU-IEI-R, Vol. 357). Linköping University Electronic Press. https://doi.org/10.3384/IEI-R.357

10. Bilagor

Not available.



RE:Source är ett strategiskt innovationsprogram som fokuserar på att utveckla cirkulära, resurseffektiva materialflöden. Vårt mål är att uppnå en hållbar materialanvändning där vi håller oss inom planetens gränser.