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SCIENCE FOR POLICY BRIEF – JRC Raw Materials Information System 2025

Product-as-a-Service as an essential enabler for circular economy in the EU

2025

HIGHLIGHTS

- The Product-as-a-Service (PaaS) model offers potential to accelerate the EU's transition to a circular economy (CE). Scientific assessment of a PaaS is essential, because not all PaaS offerings and features may contribute to a CE.
- The assessment of an example of PaaS offering for home appliances in the EU market shows positive contributions to the efficient use of critical raw materials (CRMs).
- Business leaders in the EU are recommended to investigate the potential of PaaS with inherent complexity of a PaaS in mind, including resource efficiency and sustainability potentials.
- EU policymakers are recommended to investigate possible policies for facilitating PaaS offerings of higher resource efficiency on the EU market, also for critical raw materials, for instance through providing fair assessment and labelling schemes to end users.

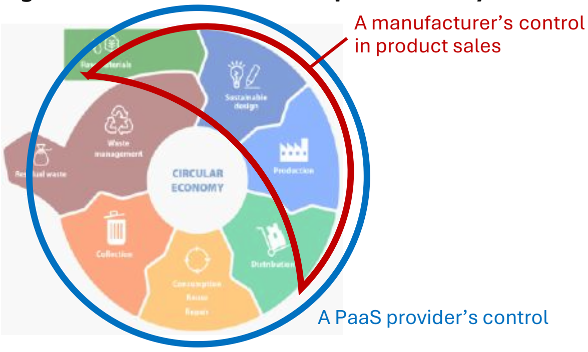
CONTEXT AND PROBLEM DEFINITION

Background

The shift towards a more circular and resilient economy is a focus of the European Commission (EC). The Circular Economy Act planned for 2026 aims to enhance sustainability by "creating market demand for secondary materials and establishing a single market for waste, particularly concerning critical raw materials (CRMs)" [1]. It will also support companies in implementing circular economy (CE) strategies, as one of the objectives of the new Clean Industrial Deal (2025). CE is indeed increasingly indicated as a means to better «exploit the critical raw materials already contained in products sold in Europe» [2]. The Joint Research Centre (JRC) is currently assessing and developing life-extension strategies for different classes of products, building upon earlier works on, e.g., batteries in electric vehicles [3]. CE strategies differ among life-extension strategies that target product streams – e.g. reuse and repurposing, service-based business

models, etc. – and second-life strategies that target waste streams – e.g. recycling and recovery of materials, improved collection schemes, etc. While second-life strategies are usually covered in the recent EU waste policy framework, life-extension strategies are not yet included in EU product policies. Yet, the Circular Economy Action Plan (CEAP, COM/2020/98) and the Sustainable Development Goals of the United Nations recommend new consumption models, including service-based ones, as key enablers for the CE. Circularity of raw materials is increasingly needed to ensure a competitive industrial transformation, according to the Clean Industrial Deal (2025). Ideally, all actors in a value chain, consumers included, have a common interest in retaining the material's value [4].
Product-as-a-Service (PaaS) [5] is a service-based business model, where the supplier keeps the ownership of the products while the end users keep access to the products (see Box 1). Some PaaS offerings have long been availed of by consumers (e.g. automobiles), while others are emerging on the market (e.g. do-it-yourself tools). PaaS differs from the traditional one-off sales of products in terms of the supplier control of the product lifecycle [6] (Figure 1). The greater control by a PaaS supplier over the product lifecycle and the supply chain can improve end-of-use processes. Also, with PaaS, the longer lifetime of the product, typically in multiple contracts, creates greater economic benefit for the supplier. The PaaS model therefore potentially fulfils many of the crucial criteria mentioned in the Draghi report [7] and Competitiveness Compass for the EU (COM/2025/30): competitive businesses with source for growth, more environmental sustainability, and resource security of critical raw materials (CRMs).

Figure 1 – The contrast in the product lifecycle control



Source: Adapted from European Parliament Research Service
Note: The control in this figure means the access to and responsiblity for the products. Even in one-off sales of products, a manufacturer has extended producer responsibility (EPR) and may run their own take-back programme at the end-of-use stage.

Box 1: Product-as-a-service (PaaS) – what is it?

PaaS is a business model where suppliers keep the ownership of the products in providing end users with offerings (i.e. products and services); the end users can avail of the product via subscription contracts (e.g. a flat-rate payment per calendar period). The suppliers may be original equipment manufacturers (OEMs). The International Organization for Standardization (ISO) TC323 on CE is expected (in 2025) to publish a technical report that will compile PaaS practices.
A PaaS supplier commits to the product functions and needs to make services, spare parts, etc., available, for the service period, e.g., 10-20 years. On the other hand, it can gain control of material flows, facilitating remanufacturing and recycling. This is in stark contrast to the current practice, where OEMs have little control over the return of the end-of-use products and even less on the quality of material recycling. Therefore, the switch to a PaaS business model has potential to increase the efficiency of CRM recovery. Key to carrying out PaaS businesses efficiently is using the right information for the right processes such as design and service. Information and communication technologies, including the Internet of Things, are effective enablers of PaaS models.

Although PaaS provides the potential to use resources more efficiently, empirically validated scientific knowledge on PaaS is relatively immature. Also, no specific incentive on PaaS is found in the EU policies, nor indication on how to frame PaaS in policy, notably in product policies; it is, hence, crucial to build a solid EU knowledge base on PaaS.

Expectations on Product-as-a-Service

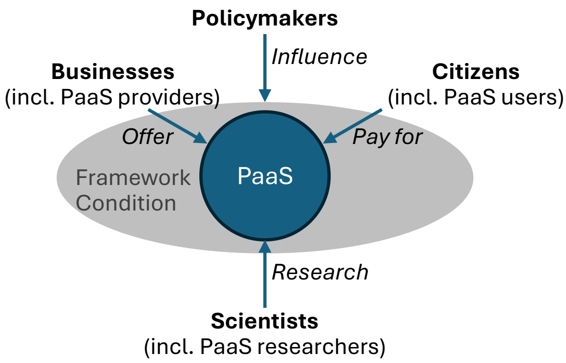
Globally speaking, industries recognise PaaS as a potential means for increasing resource efficiency. For instance, the World Economic Forum [8] discusses the need for a system upgrade towards CE. In the discussion, PaaS is brought up as a potential model (e.g. lighting-as-a-service and computer-as-a-service), because it creates an incentive to keep the value of the products for as long as possible, extend the lifetime, and reduce waste. It also stresses the importance for products

to be returned to the supplier at the end of the contract, to reduce the risk of non-optimal product handling of products by non-professionals. The World Business Council for Sustainable Development (WBCSD) states that businesses can play a role in the CE and recommends innovation with process, product, and business models, where PaaS is introduced (e.g. tyres-as-a-service) [9]. From the environmental perspective, the United Nations Environment Programme (UNEP) [5] explains the need for wellbeing decoupling, i.e. increasing the services delivered per unit of resource use, and introduces PaaS as one of the promoted business models. In facilitating further development of innovative circular business models, including PaaS, incentives through regulation and financial incentivisation are considered potentially effective. Also, UNEP recommends PaaS that developers learn from cases where this approach has not proven to generate net environmental benefits [10].
Individual companies have experienced the potential of PaaS for more than two decades: the blended offers of products and services was explained in the context of business-to-business marketing [11]. An example is an offering by Rolls-Royce of 'Power By The Hour' aircraft engines, which include services in the offering and charge based on the number of hours in which the engines were in operation rather than based on the number of engines [12]. Another well-known example is lighting-as-a-service [13]. PaaS is considered to enhance manufacturers' competitiveness because of additional elements of an offering, including attractive customer training services [14]. Applications to batteries in industry [15] are also discussed. Further, PaaS can be seen in cases where multiple end users access a pool of products simultaneously (e.g. carpooling), which promotes collaborative consumption [16].
In business-to-consumer markets, PaaS can also support consumers' environmental awareness [17] for example when professional actors take care of end-of-use products. Across product categories, substantial differences are reported; for instance, between clothing, mobility, and tools [18]. Hence, lessons learned from a product category cannot be simply transferred to other product categories. Further, the analysis of the photovoltaic sector, indicated that several aspects can be both drivers and barriers (e.g. the all-inclusive feature can be seen as both hassle-free offering and reduced flexibility) [19]. Thus far, overall, PaaS has been applied on small scales, with one of the main challenges being on the financial aspect. Recently reported is a tailored design of a PaaS tackling energy poverty, which is a social concern: a PaaS in Belgium provides socially vulnerable people with energy-efficient home appliances thanks to the involvement of a social enterprise partnered with the appliance manufacturer [20].
From the environmental perspective, a PaaS has been considered a promising measure for decoupling resource use and the economy [21]. A review [22] reports that assessments by scientists often resulted in PaaS positive effects on environmental sustainability. One research paper reported that lifecycle CRM efficiency in washing machines increased by 40% thanks to the prolonged service lifetime and better-controlled recycling [23]. Inherent uncertainty of PaaS (e.g. user behaviour uncertainty) needs to be thoroughly assessed. Therefore, assessment methods for PaaS, for instance, using system dynamics, have been developed [24] to incorporate dynamic user behaviour [25]. Research on design implications is also underdeveloped in research and insights are missing as to which parameters are more effective design measures.

Problem Statement

Policymaking enabling more actionable support for circular business models, including PaaS, would be needed in setting the level playing field where new circular business models may be introduced and tested [26]. Challenges for PaaS are identified from the perspectives of major PaaS stakeholders – businesses, scientists, policymakers and citizens – of current relevance for EU policymaking, as shown in Figure 2. First, from the citizens' perspective, there is a lack of a scheme for making comparison on sustainability both between one-off sales of products and PaaS and within PaaS offerings, e.g. via labelling. Consequently, end users tend to make purchase decisions with insufficient information. One reason for this void is the knowledge gap on which sustainability and circularity metrics could be relevant for PaaS offerings. Although individual assessment on a case at hand is required for sustainability assessment [27], relevant metrics and common dynamics may be captured for typical PaaS offerings (e.g. the reuse ratio of products and components). Second, from a business viewpoint, the current EU regulations are unclear in terms of how PaaS is addressed. For instance, the Ecodesign for Sustainable Products and Energy Labelling Working Plan 2025-2030 plans to address sustainability performance of a significant number of final and intermediate products but PaaS offerings are in principle not covered [28]. The Batteries Regulation, (EU) 2023/1542, states that batteries placed on the market and put into service shall comply in the same way with the Regulation requirement but does not indicate specific provisions for batteries put in service, e.g. in relation to PaaS strategies. Likewise, the CRM Act (EU) 2024/1252, does not explicitly mention PaaS, although it incentivises business practices that could facilitate an economically feasible recovery of CRMs. Also, the lack of comparability on sustainability mentioned above hinders manufacturers' ecodesign [29]. Consequently, potential loopholes and risks of greenwashing exist [30, 31]. Further, how the cost to handling end-of-use products is borne under the extended producer responsibility (EPR) scheme does not adequately incorporate PaaS settings. Third, from a research viewpoint, earlier scientific research on CE, including PaaS, demonstrated conceptual advancement [26] but more evidence-based knowledge needs to be developed in order to demonstrate (and unleash) the full circularity potential. A reason for the still incomplete knowledge may be the inherent challenges for researchers to access business-sensitive data on real PaaS offerings.

Figure 2 – Major PaaS stakeholders of relevance



Source: own elaboration

Research Conducted

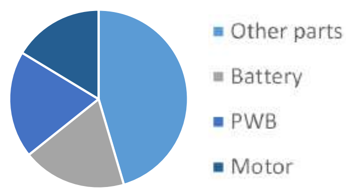
Intention of the research

New research on PaaS has been conducted by scientists to address the challenges explained above. Regarding the difference between a PaaS and its counterpart, one-off sales product, a comparison has been made of the resource efficiency of home appliances in the EU market. Home appliances belong to the category of electr(on)ic equipment that are known to contain significant quantities of CRMs. For the challenge related to indicators, new scientific knowledge regarding key parameters that influence the resource efficiency of the PaaS is presented below. Because of the EU's interest in CRMs, e.g. with the CRM Act (EU) 2024/1252, this research intends to focus on analysing the efficiency, through PaaS, of the use of CRMs and not of all materials. Noticeablt, the possible loss of energy efficiency due to lifetime extension against technological advancement [10] is not discussed in this analysis.

Data and method used for the research

The research was carried out in close collaboration with the original equipment manufacturer (OEM) based in the EU that provides the PaaS of a widely used product - a handheld battery-operated vacuum cleaner [32]. The following motivations justified the product choice: the presence of CRMs in the product and the number of products used in the EU consumer market (greater PaaS potential). The focus on CRMs has motivated the use of material flow analysis (MFA) as the method to capture stocks and flows and assess the resource efficiency. MFA is an analytical method used to quantify flows and stocks of materials and substances in a defined system. The data was collected mainly in 2024.

Figure 3 – CRM mass per component in the case product



Source: own elaboration

The total mass of CRMs in the vacuum cleaner is ca. 647 g (the mass of the whole product is ca. 4 kg). Figure 3 shows the portions, in terms of mass, of the battery (19%), the printing wiring board (PWB) (19%), and the motor (16%) as components, besides other parts (45%) with, e.g., aluminium and copper. The technical lifetimes of the components were provided by the OEM: 3 years for the battery and 12 years for the motor and the PWB. Two scenarios, realistic for the vacuum cleaner, were made in consultation with the OEM, as explained in Table 1. The material flow of the PaaS scenario (two lives with recycling) is depicted in Figure 4: the inflow to the focal system (labelled as input material) is equal to the sum of the flow to the recycled material stock and the leakage to the environment. The leakage includes uncollected products, unextracted components after collection, and unrecovered portions in the recycling process.

Table 1 – Description of the two scenarios

Scenario	Description
One-off sale	The product is purchased and owned by an end user. At EoL, after 5 years, the product should be brought to a municipal waste-sorting station.
PaaS	The product is owned by an end user via a 6-years subscription contract. At the end of the contract, the service supplier keeps the product ownership. Some components are reused for the product's second life.

Source: own elaboration based on [32]. EoL = end-of-life

Key data used for the material flow analysis is shown in Table 2: PaaS offerings in principle present higher circularity performance, notably for collection but also component extraction and re-use rates. In the case of product sales, the key data is as follows. The ratio of the collected products that come to end-of-use is 41% based on the Dutch WEEE flows for small equipment [33]. Meaning that 59% of the products do not go into appropriate collection channels or are discarded and therefore are considered to leak to the environment. The ratio of the extracted components at recycling facilities is assumed to be 70%. No component reuse will happen in this case. On the other hand, with PaaS, as per WEEE Directive provisions for industrial products, 100% of the products is collected at the end of the contract by the PaaS-providing company, who can then extract components with enough remaining life suitable for reuse. We can assume that the extraction ratio is 100%, because the PaaS supplier (the product designer and manufacturer in this case) owns the product data. Some components may not pass the criteria for reuse: hence, the component reuse is assumed 90%.

Results

The MFA results for the materials in the three main components (i.e. the battery, the motor and the PWB) are summarised in Table 3 [32].

Table 2 – Key data used for the Material Flow Analysis

Parameter	One-off sale	PaaS
Product collection rate	41%	100%
Component extraction rate	70%	100%
Reuse rate of components	0%	90%
Recovery rate in recycling	No difference as it depends on the material.	

Source: own elaboration

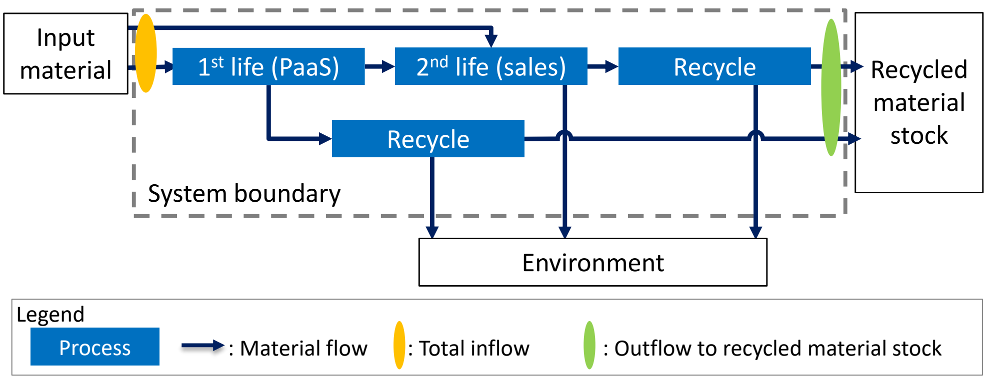
The total inflow (g / year) of the PaaS compared with the one-off sale was calculated at between 50% and 97%, (see Table 3): the PaaS outperforms the one-off sales with respect to all substances and particularly for some substances. The outflow (g / year) is divided into the materials that are recycled and materials that leak to the environment (as depicted by Figure 4). The former ratio is higher in the PaaS than in the one-off sales (for Al and Cu as an example, 52% in the PaaS and 18% in the sales). Meaning that the PaaS also improves the material outflow. To identify key influential parameters on the resource efficiency in the PaaS, a sensitivity analysis was performed. For the total inflow (shown in Table 4), the CRM mass in the component is influential; also, the higher the number of units used for the temporary boundary, the higher the sensitivity (four units of the batteries and one unit of the PWB and the motor are used for the whole period). The longer the PaaS lifetime, the lower material inflow to the system, and the sensitivity

Table 3 – Overall results of the material flow analysis

	Al, Cu	Co, Li, Mn, Ni	Dy, Nd	Bi, Mg, Ti
Component	**(Other parts)**	**Battery**	**Motor**	**PWB**
One-off sale	**100%**	**100%**	**100%**	**100%**
To recycling	18%	9%	0%	0%
To landfill	82%	91%	100%	100%
PaaS	**75%**	**97%**	**50%**	**50%**
To recycling	52%	49%	8%	3%
To landfill	48%	51%	92%	97%

Note: 'Landfill' also includes other processes such as illegal disposal.
Source: own elaboration based on [32]. EoL = end-of-life

Figure 4 – The material flow of the PaaS scenario



Source: own elaboration

depends on the mass of the CRM. The recovery rate in recycling has no influence on the inflow (by definition, it influences the outflow to the stock; see also Table 5). The component reuse rate is influential only when the reuse takes place. For the substances in a reused component, the sensitivity of the component reuse rate is larger than the PaaS lifetime by one order of magnitude. The required investment for achieving the parameter calibrations is not considered.

Table 4 – Sensitivity for the total inflow

Calibrated parameter (unit)	PWB Bi	Co	Motor Nd	Battery Co	Li
Mass in a product (g)	0.10	0.10	0.10	0.36	0.36
PaaS lifetime (year)	-0.0038	-0.0032	-0.23	-0.55	-0.20
Recovery rate in recycling (-)	0	N/A	0	0	0
Component reuse rate in PaaS (-)	-0.038	-0.032	-2.3	N/A	N/A

Source: own elaboration
Note: N/A refers to not available due to the division by zero

Table 5 – Sensitivity for the outflow to recycled material

Calibrated parameter (unit)	PWB Bi	Co	Motor Nd	Battery Co	Li
Mass in a product (g)	0.028	0	0.032	0.21	0.098
PaaS lifetime (year)	-0.0011	0	-0.072	-0.32	-0.053
Recovery rate in recycling (-)	0.0038	N/A	0.23	3.1	1.1
Component reuse rate in PaaS (-)	-0.031	N/A	-2.1	N/A	N/A

Source: own elaboration
Note: N/A refers to not available due to the division by zero

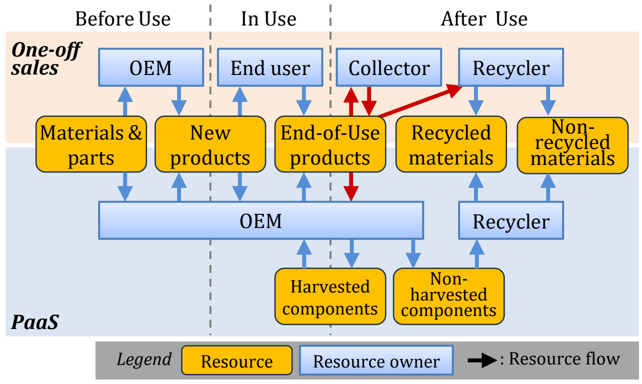
For the outflow to the recycled material stock (Table 5), the recovery rate is most influential. Mass in the product is influential but depends on the recovery rate (zero for Co of a PWB). The component reuse rate and the amount of the material that flows to the recycled material stock have a trade-off relationship, when reuse takes place, and the recovery rate is not zero.

The main implications from the sensitivity analysis are the following: i) improve the inflow and outflow of batteries, ii) increase the reuse rate of the motors, iii) increase the PaaS lifetime, and iv) keep in mind the trade-off relationship between reuse and recycling.

Implications

The provided account of the stocks and flows of the CRMs of a PaaS in the EU market in comparison with a one-off sales product implies the following. The PaaS case outperforms the sales, according to the scenarios developed in consultation with the OEM providing the PaaS. The major reasons for the better performance are: i) better conditions of PaaS for the product collection ensured by the PaaS contract, ii) better conditions of PaaS for the component extraction thanks to the limited variety and uncertainty of the collected products, and iii) exploitation of longer (fuller) component lifetimes in PaaS through component reuse. These reasons all point to the entity first accessing end-of-use products: this is the OEM in the PaaS case, and the end users and then collectors in the sold product cases. OEMs can harvest components more efficiently for reuse. Figure 5 displays this contrast. Implications for OEMs as a PaaS supplier are presented regarding what they can implement to improve the resource efficiency. OEMs have a unique position as they have control of product design and production and control of service design and service delivery. These features are represented in relation to the four parameters used in the sensitivity analysis in Table 6, which compares the superior performance of providing PaaS with one-off sales.

Figure 5 – The contrast between one-off sales products and PaaS regarding the access to end-of-use products.



Source: own elaboration

Table 6 – Comparison between PaaS and one-off sales

Parameter (unit)	Product sale	PaaS
Mass in a product (g)	Controllable through product design	Controllable through product design
PaaS lifetime (year)	Not controllable	Controllable through products and services
Recovery rate in recycling (-)	Not controllable	Not fully controllable (unless OEM has a recovery process)
Component reuse rate in PaaS (-)	Not controllable	Controllable through products and services

Source: own elaboration

The sensitivity analysis showed that the four parameters may or may not influence the resource efficiency depending on several conditions. The major conditions are i) if the component's technical lifetime is longer than the product lifetime and ii) whether the material recovery rate is substantial. Using these two conditions, the best options to improve resource efficiency in PaaS are shown in Table 7: if the component reuse is technically possible and/or the material recovery is feasible, more options are available. If the component reuse is technically impossible (e.g. battery of the vacuum cleaner, due to the shorter battery lifetime) and the material recovery is not feasible (e.g. cobalt in a PWB), the options are limited. It should be emphasised that listing the options is simplistic and systemic relationships are invisible in the table. For instance, reducing the mass of a material may negatively impact the product or component lifetime. The complexity caused by systemic relationships must be kept in mind. Also, for specific product categories, additional factors may need to be considered. For instance, for products with faster innovation cycles, the component's compatibility with multiple product generations must be ensured for the component reuse.

Table 7 – Options to improve resource efficiency in PaaS

		Recovery in material recycling feasible?	
		Yes	**No**
Component reuse possible?	**Yes**	Reduce mass by design Increase PaaS lifetime Increase recovery rate Increase reuse rate	Reduce mass by design Increase PaaS lifetime Increase reuse rate
	No	Reduce mass by design Increase PaaS lifetime Increase recovery rate	Reduce mass by design Increase PaaS lifetime

Source: own elaboration

Recommendations

This policy brief proves the potential of PaaS to improve resource efficiency, despite various challenges, including insufficient transparency on performance. Researchers identified the limitations of the current policies for influencing design and facilitating circular business models [34, 35]. An underlying approach relevant to PaaS is extended producer responsibility (EPR) [36]: even though PaaS typically includes OEMs' responsibility of end-of-use products, OEMs pay a fee to producer responsibility organisations. PaaS associated with EPR as a key CE enabler needs to be further investigated [37]. Another study on PaaS and related policies [29] suggests interventions regarding product suppliers' system responsibility, market conditions, digital infrastructure, and regulatory conditions. Recommendations include the followings:

- **To academia**: to develop robust indicators to assess the performance (e.g. resource efficiency) of PaaS offerings, also in comparison with one-off sales.
- **To businesses:**
  - To collect and consolidate data on PaaS case studies, regarding their sustainability and circularity performance;
  - To design and adapt their PaaS offerings to maximise resource efficiency.
- **To policymakers:**
  - To include PaaS in circular economy strategies also to improve EU competitiveness and resilience, including for critical raw materials;
  - To promote the definition of criteria to assess circularity and sustainability of PaaS;
  - To allocate resources to understand, develop, and support the implementation of PaaS.

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Note for the sensitivity analysis

The sensitivity was calculated by calibrating an input parameter with an increase of 1% of its current value; see the following formula. Sensitivity = $\Delta y / \Delta x$, where x is one of the four calibrated parameters in Tables 4 and 5, and y is, for a substance of a component, either a) the total inflow (g / year) or b) the outflow to the recycled material stock (g / year).

Disclaimer or other final details

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