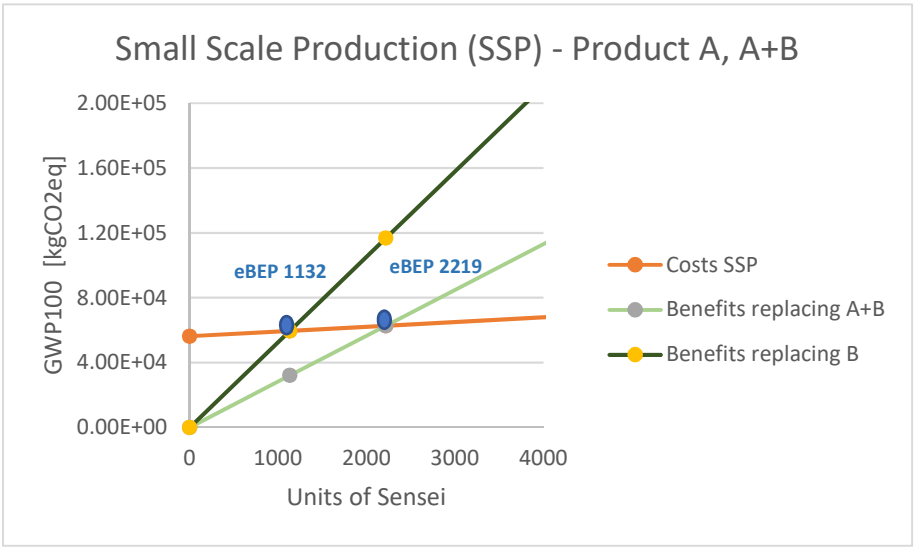
RESMAC: REpurposing of SMArtphone Capabilities

WP4: Feasibility and sustainability study of volume-production scenarios



Environmental Break Even of Sensei:

When environmental benefits offset costs

Cover Image designed by BOID

Leading Partner of WP4: Industrial and Materials Science Department at Chalmers University of Technology
Corresponding author of WP4 deliverable: Ilaria Barletta, ilaria.barletta@chalmers.se

Contents

Executive summary 4
1. Environmental sustainability analysis 6
1.1. *Sensei* - The product concept in object and competing product systems 6
1.2. Environmental sustainability of Sensei's business model based on volume scenarios 7
1.2.1. Life cycle assessment: modelling choice 7
1.2.2. Definition of volume scenarios 8
1.2.3. Environmental product data – Sensei and competing product systems 12
1.2.4. Break-even analysis 15
2. Feasibility of the business model 20
2.1. Product costs 20
2.2. Existing Barriers and Potential for Sensei's business model success 21
References 24
Appendix A 25
Appendix B 26

Figures

Figure 1: Sensei. From left to right: front, back and side view. Illustration by Boid. 6
Figure 2: An example of the range of functionalities Sensei provides. Illustration by Boid. 6
Figure 3: Lil tracker, a GPS tracking watch for kids (liltracker.com). Example of product system A in the environmental analysis in ReSmaC. 7
Figure 4: Vivint Sky smart home system. Example of product system B in the environmental analysis in ReSmaC. 7
Figure 5: Flows and stocks of Sony smartphones' end of life in a Belmont Trading facility. Numbers relate to a 1-year time. Illustration realized by CIT. Data from interview with Johan Larsson (Sony). 10
Figure 6: The four volume scenarios used in the ReSmaC environmental analysis, made up by crossing "product competitiveness" and "production capacity". 11
Figure 7: Environmental breakeven points for SSP scenario 18
Figure 8: Environmental breakeven points for SSP scenario, substitution of Product A and Product A+B only 18

Tables

Table 1: Estimated Global Warming Potential (GWP) of Sensei per life cycle stage in a 3-year lifetime... 12
Table 2: Sensei's competing products systems and components' weight... 14
Table 3: GWP of the product systems that compete with Sensei. ... 14
Table 4: Environmental benefits of Sensei in substituting one or more competing product systems... 15
Table 5: Fixed environmental costs per volume scenario, in the 3-year lifetime of Sensei. ... 16
Table 6: Variable environmental costs per volume scenario... 16
Table 7: Environmental breakeven of Sensei in different volume scenarios and competitiveness scenarios ... 17
Table 8: Product and production cost per a unit of Sensei. Data provided by Boid for the most... 20
Table 9: Bill of material of Sensei... 25
Table 10: Usage parameters of Sensei... 25
Table 11: Estimated Global Warming Potential (GWP) of Sensei per life cycle stage in an average 3-year lifetime.. ... 26
Table 12: Sensei's production parameters and variables. ... 28
Table 13: Transportations parameters and variables. ... 29

Executive summary

Disclaimer: this is a public version of the project report. Sensitive information of industrial partners has been blocked out through the text "xxx".

Aim of the work package and links with previous work packages:

Work Package (WP) 4 results in the following outputs:

- A sustainability analysis of Sensei (the product concept designed in the project's WP3) in comparison to competing products on the market produced with brand-new components. Sensei is a multi-purpose, wearable sensor that alerts the user of any relevant move of the object Sensei is attached to. The two products competing with Sensei are: a baby tracker and a smart home security system.

- Evaluation of the business model of Sensei in terms of:
  - Estimated industrial costs
  - Consideration of the barriers to Sensei's circular business model.
  - Recommendations to foster Sensei's circular business model.

Methodology:

The sustainability analysis relied on two volume scenarios: one for small-scale production and one for mass production. These two volume scenarios have been "crossed" with three cases: Sensei substituting a brand-new baby tracker, Sensei substituting a brand-new home security system and Sensei substituting both products during its lifetime. This configuration resulted in six scenarios of analysis. A few data necessary for the environmental evaluation came from the project's WP2 deliverable. Most of the data has been retrieved from databases and scientific articles and, if needed, re-elaborated by following detailed assumptions.

Key findings:

After analysing Sensei's production and its sell volumes, two outcomes have been drawn: the first one describes the best-case outcome, i.e., when the investment in realizing, using and dismissing Sensei paid off (in terms of environmental costs) with the fewest number of units of Sensei possible. The second one is the worst-case outcome, i.e., when the investment in realizing, using and dismissing Sensei paid off (in terms of environmental costs) with the highest number of units of Sensei possible.

- Best-case outcome: Sensei substitutes a smart security home system and is produced at a small-scale production. In this case, **Sensei pays off** its environmental burden after its **first half of the year** on the market, and starts adding environmental benefits **from the** xxx **unit being sold.**

- Worst-case outcome: **Sensei** substitutes a baby tracker and is mass produced. In this case, Sensei **pays off** its environmental burden as it is about to end its second years of sells (**2.8 years**), and starts adding environmental benefits **from the** xxx **unit being sold.**

The **main barriers** to the development of Sensei's business models and in general, to the development of circular economy strategies for the reuse of ICT products are:

- No update on the WEEE Directive in the aftermath of European "circular economy" reformation
- WEEE Directive still focused on recycling targets, that are, on top of that, difficult to meet.
- High uncertainty in product quality and product volumes from take-back schemes

A set of potential interventions for weakening the aforementioned barriers has been illustrated in the last chapter of the report.

The **recommendations** that the author of this report gives to the future Sensei's producer and producers of existing similar products boil down to the reduction of the environmental impact of the product, by:

- Acquiring less material-intensive machinery (e.g., additive manufacturing would be proper for a small-scale and low volume scenario)
- Acquiring used machinery (e.g., injection moulding machine) as a result of an extended life-time strategy
- Optimizing shipping routes for deliveries to customers
- Sizing the production facility after getting an accurate market analysis that validates the business model. An oversized production facility would make product's economic and environmental costs skyrocket.
- Communicating the environmental performance of the product in order to increase a customer base made up of environmentally conscious customers.

1. Environmental sustainability analysis

1.1. *Sensei* - The product concept in object and competing product systems

Sensei (Figure 1) is the product been designed in ReSmaC and presented in WP3. Sensei is a multi-purpose, wearable sensor that alerts the user of any relevant move of the object Sensei is attached to via a dedicated smartphone app.

Figure 1: Sensei. From left to right: front, back and side view. Illustration by Boid.

The main goal of WP4 is evaluating if and under which conditions Sensei's introduction to the market is environmentally beneficial.

Figure 2 illustrates Sensei's applications. Sensei can be used for tracking babies' movements, sleep patterns and as alarm for security purposes.

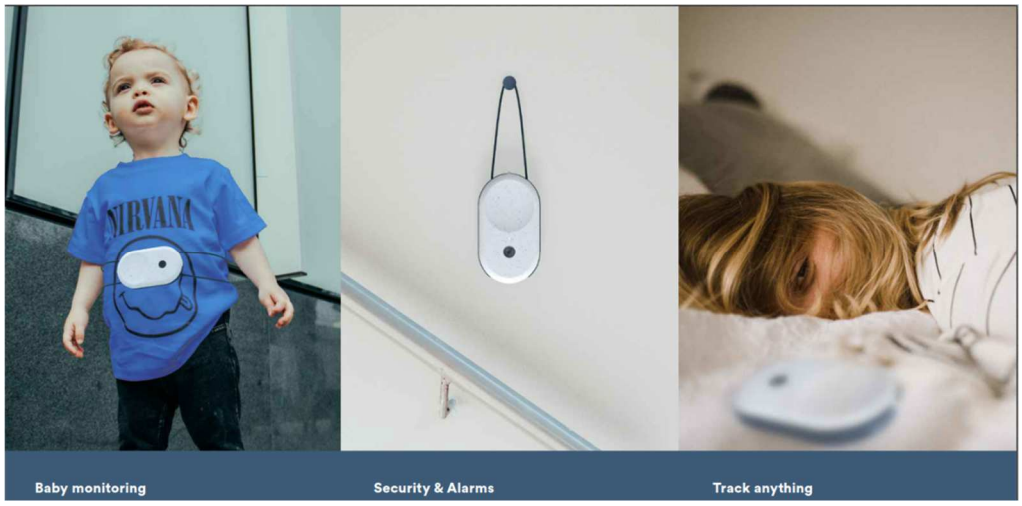


Figure 2: An example of the range of functionalities Sensei provides. Illustration by Boid.

The multi-functionality of Sensei makes its marketability more appealing, but also makes the comparison with alternative product systems challenging. Two already-existing products have

been used for the environmental cost-benefit analysis of Sensei VS competing product offering the same functionality.

For the functionality of baby monitoring (functionality A), the most representative product similar to Sensei (aka, a wearable device) is a wrist watch for babies embedded with GPS/Bluetooth locator and connected to an iOS or Android application (Figure 3 depicts what will be indicated as **product system A** in the analysis).

Figure 3: Lil tracker, a GPS tracking watch for kids (liltracker.com). Example of product system A in the environmental analysis in ReSmaC.

For the home security functionality (functionality B), a tablet-based, smart-home system has been chosen, as the one displayed in Figure 4 (**product system B** in the analysis).

Figure 4: Vivint Sky smart home system. Example of product system B in the environmental analysis in ReSmaC.

A fictitious product-system C, competing with a sleep tracker already existing on the market, has not been considered in the analysis. The reason for excluding it is two-fold: the close similarity in terms of product design with product-system A (in case of a product designed exactly for the sleep-tracking purpose), and the assumption that the demand of smartphones and smartwatches would not be affected by the introduction of Sensei. Further considerations about volume scenarios can be found at page 8. Details about the simplified bill of material of product system can be found in Table 2 at page 14.

1.2. Environmental sustainability of Sensei's business model based on volume scenarios

1.2.1. Life cycle assessment: modelling choice

The cornerstone methodology to calculate environmental costs and benefits of Sensei vs its competing products is the life cycle assessment (LCA) methodology, whose framework is standardized by the ISO14044:2006 (2006). There are two different approaches for delivering an

LCA: analysis: attributional and consequential. Each of two approaches must be used for specific purposes, as it answers two different sets of questions.

The attributional approach aims at accounting the total of the allocated shares of the activities that have contributed to the production, consumption, and disposal of the product system in object (functional unit). In ReSmaC's case, an attributional LCA would bring about the calculation of the environmental footprint of Sensei, a baby tracker and a smart-home security system.
Using a stand-alone attributional approach in ReSmaC would not be dramatically insightful in delivering an environmental cost-benefit analysis.
In fact, it is obvious that Sensei's footprint is "lighter" than the footprint of a brand new baby tracker (product system A), which is in turn less heavy than the footprint of a brand new smart-home security system (product system B). Equation 1 represents this inequality.

$$Env\ Footrpint_{\ sensei} < Env\ Footrpint_{\ product\ A} < Env\ Footrpint_{\ product\ B} \quad (1)$$

What matters in ReSmaC's case is the collective environmental footprint of not only Sensei's market, but also the market of its competing products, i.e., the extent to which Sensei's market demand influences the individual demands of product system A and product system B. This is what the LCA consequential approach aims at finding out.
In the consequential approach, what is being calculated is the collective environmental footprints that are expected to change because of a change in demand for the functional unit, in this case, a unit of Sensei. This means that data on marginal supplies and substitution of displaced activities are accounted in the cost-benefit analysis. This also entails that more than one volume scenario needs to be modelled in the analysis, given the intrinsic uncertainty of Sensei's, product A's and product B's market demand.

1.2.2. Definition of volume scenarios

Four assumptions underlie the scenarios' definition:

i. **Brand-new smartphones' demand is not affected by Sensei,** as Sensei indeed results from producers' take back schemes and the extension of subscription renewals by telecommunication providers. This means that +1 unit of a brand new smartphone will always be produced, bought and used irrespective of Sensei's introduction to the market.

ii. **Sensei's demand is tapped by the availability of used smartphones' components.** This means that Sensei's producer cannot guarantee unlimited and constant supply of

Sensei units, as the producer relies on the amount of available components from bought-back smartphones that are suitable for repurposing.

> In this analysis, the percentage of smartphones whose components are suitable for Sensei out of the total amount of bought back smartphones is indicated with the parameter ***r***[1].

iii. **The relationship between a unit of Sensei and a unit of smartphone suitable for Sensei is 1:1.** This means that the calculations of environmental costs and benefits assume that if a smartphone is suitable for repurposing, then all its key components are suitable to build a unit of Sensei. This assumption does not apply to all cases in reality, where a smartphone might have the PCB still functioning but not the camera, for instance. However, this assumption would avoid an over-proliferation of scenarios to be analysed, but has to be considered as leading to an optimistic output, environmentally wise. More conservative assumptions and considerations, laid in the following part of the report, can contribute to counterbalance the favourable position of a 1:1 relationship between a smartphone and a unit of Sensei.

iv. **Sensei erodes the market share of product A and product B**. This means that the total market size of baby trackers and the total market size of smart security alarms stay unvaried. This assumption is reasonable when two circumstances take place: 1) no contingency factors trigger increased demand for product A or product B (i.e., no increased natality rates and no increased need for home security) and 2) when a successful market campaign of Sensei makes the customer favour it over product A and product B.

The value of the parameter r – ranging from 0 to 1 – would cause outputs of the analysis that may greatly differentiate between each other. The to-be developed scenarios would underpin a sub-set of scenarios having low r and the other one having high r. It is therefore necessary to understand what value between 0 and 1 would be representative of a low value of r and what value between 0 and 1 would be representative of a low value of r.
An internal investigation carried out by Sony and Chalmers Industriteknik (CIT) aimed at identifying a number of Sony smartphones whose components are suitable for Sensei and processed in Belmont Trading on an annual basis. The flows and stocks have been depicted in Figure 5 (next page). A starting number of xxx phones reaching a Belmont Trading facility in Karlskoga would be progressively shrunk to 1/5 of xxx units suitable for Sensei. These phones are less than 2 years old and are so that today go to materials recycling, as they do not qualify for

reuse.

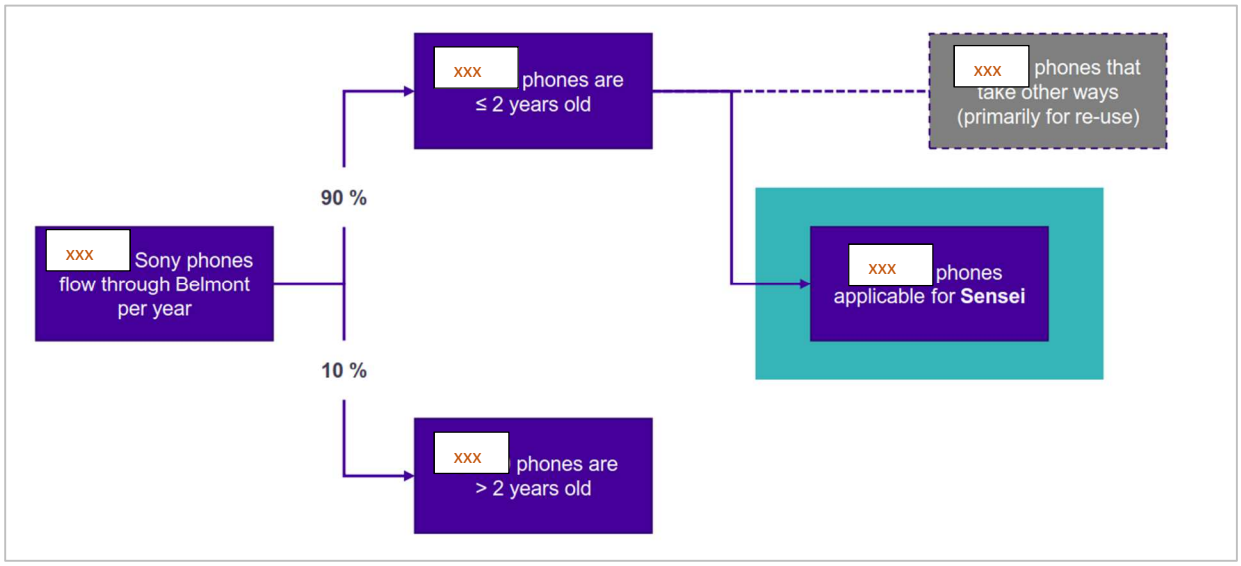


Figure 5: Flows and stocks of Sony smartphones' end of life in a Belmont Trading facility. Numbers relate to a 1-year time. Illustration realized by CIT. Data from interview with Johan Larsson (Sony).

A further testing and evaluation would save the 80% of them, bringing to an **ultimate amount of** xxx **units**[1]. This amount constitutes 16% of the initial amount of bough-back devices, only considering Sony's brand as manufacturer. If we accept Sony's figures as representative for the Swedish smartphones' end-of-life market, r would be equal to 16%.
Since ReSmaC aims at involving other smartphone brands that allow for manipulations of the device by third parties, and since figures about the end-of-life market of smartphones in Sweden are unknown[2], r is brought to range as follows:

- a worst-case scenario of 10% (**low r = 10%**)
- a best-case scenario of 20% (**high r = 20%**).

It is now possible to boil down four volume scenarios: scenario 1, scenario 2, scenario 3, and scenario 4, represented in Figure 6 (next page). The first dimension is represented by the degree of competitiveness of Sensei (aka, whether it replaces product system A or B[3]), whereas the second dimension indicates the amount of components at stock, given an either high or low value of r. In Figure 6, the red cell of the matrix labels scenario 2 as the worst scenario, among the four,

[1] These units constitute the available capacity for Sensei's production given the availability of its components. It does not represent an estimation of yearly-sold units.
[2] For knowing more about the current state of smartphones' end of life, please read ReSmaC's WP2 Deliverable.
[3] Another scenario that has been not represented at this stage of the report but that will be modelled in the environmental analysis is Sensei replacing both product system A and B.

environmentally wise, whereas the green cell of the matrix labels scenario 4 as the best scenario, among the four, environmentally wise.

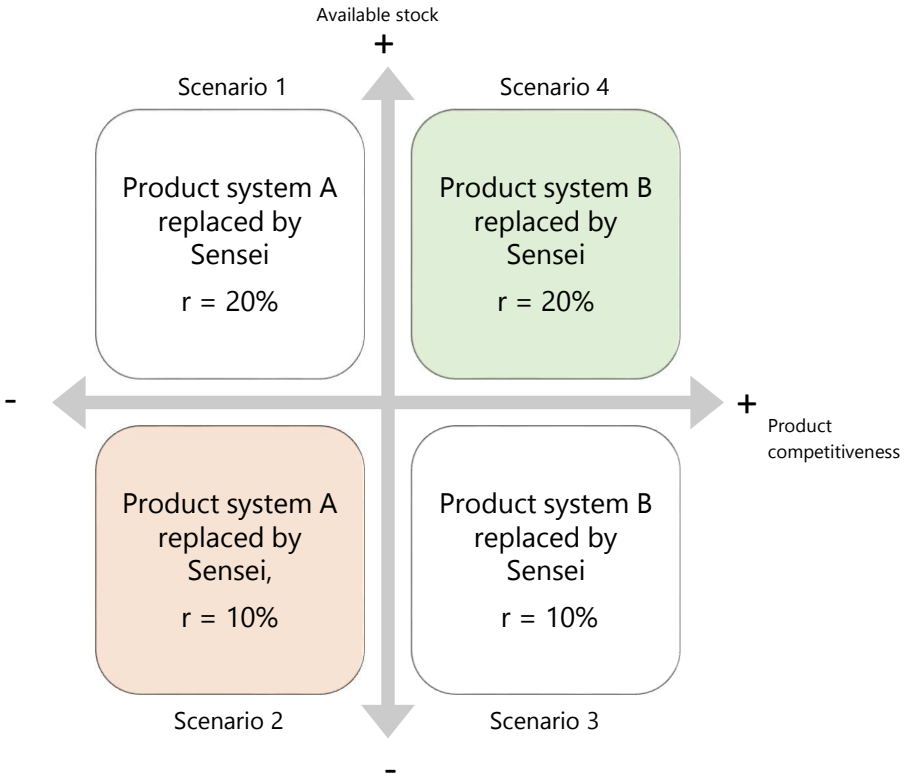


Figure 6: The four volume scenarios used in the ReSmaC environmental analysis, made up by crossing "product competitiveness" and "production capacity".

The four scenarios of Figure 6 would serve to draw future preliminary figures of the absolute amount of smartphones that are suitable for Sensei in a certain period (e.g., a year) and the extent of Sensei's environmental benefits. They do not give an indication of the production scale of Sensei[4] and how it varies over time if Sensei's business model would prove to be profitable. Because of that, two volume scenarios have been generated and used in the environmental analysis.

- An initial small-scale production scenario, occurring via additive-manufacturing processes. This scenario is labelled as **SSP** (small-scale production) **scenario**.

[4] Components for Sensei can be in fact kept in stock and produced at a later stage.

- If the business model will be profitable and the demand will be consistently increasing, a mass production via injection moulding processes would satisfy the customer demand. This scenario is labelled **MP** (mass production) **scenario**.

In the attempt to give those scenarios preliminary figures, the estimation is as follow: a **SSP would produce from 2000 to 5000 units of Sensei per year**, whereas a **MP would produce from 50000 to 80000 units of Sensei per year.**
This estimation needs future validation in the course of the prototyping phase and the fine-tuning of the business model. The points to be validated are whether the market demand will grow from SSP to MP according to the figures above and, provided that the market demand exists, whether the facility where Sensei production takes place can keep up with this demand.

1.2.3. Environmental product data – Sensei and competing product systems

Sensei

Sensei's product data in terms of bill of material and usage may be found in Table 9 and Table 10 at page 25 (Appendix A). **Error! Reference source not found.** 1 shows the global warming potential (GWP) per each of the life cycle stages of Sensei.

Table 1: Estimated Global Warming Potential (GWP) of Sensei per life cycle stage in a 3-year lifetime.

GWP_{100} [kg CO_2e]	Case production	Assembly	Transportation	Use	End of Life	**Total**
SSP scenario *min 2000 units/year*	3.02	6.68	0.44	1.2	1	**12.32**
MP Scenario *max 80000 units/year*	0.43	1.25	0.13	1.2	1	**3.98**

The numbers in Table 1 derive from either:

- Calculations in the OpenLCA piece of software using Ecoinvent database, version 3. Primary data about product design and product usage is used in order to come up with the life cycle impact category (LCIA) values, such as the GWP of the product.

- Or, estimations made from results of LCA analyses of scientific sources and elaborated according to specific, declared assumptions.

The reader who would like to know the sources of the values in Table 1 and the calculation procedures employed to obtain the final figures, is invited to read Appendix B at page 26.

It is not surprising that using high-material intensive and high-energy intensive processes and equipment on a higher number of units will reduce the individual GWP per Sensei. In fact, from a GWP perspective, Sensei produced in the MP scenario is around 1/3 less carbon intensive than the one realized in the SSP scenario. Sensei's impact in the SSP scenario is in turn around 1/3 less carbon intensive than a Sony Xperia T without accessories (45 kg CO_2e) (Ercan 2013). This also looks reasonable, given the reduced functionalities of Sensei in comparison to the ones of a smartphone and the consequent reduced power requirements.

The measurements about the assembly stage in Table 1 and the production of the injection moulding machine (see Appendix B) should be taken cautiously, since assumptions about the facility and the equipment have been made with no reference to a real case of a production of a product similar to Sensei. As mentioned in the previous page, the most important parameter that needs validation is the configuration of the facility, especially for the MP case. Would the facility 's configuration that has been hypothesized be it be able to keep the production up facing a demand of 80000 units per year? (demand which satisfies Sensei components' availability). In fact, it might be possible that more floor space (m^2) is needed, and/or more equipment is needed. This aspect can be validated in a future prototyping stage via discrete event simulation. A use test of an actual Sensei's prototype would also help to make the use-phase measurement more accurate (e.g., frequency of phone battery recharge, model of different user behaviours).

On absolute terms, giving the figures in Table 1, producing a unit of Sensei in the SSP scenario is equal to driving a gasoline car from Göteborg to Falkenberg (104 km), whereas producing a unit of Sensei in the MP scenario is equal to driving a car from north Göteborg to Särö (34 km).

Competing products: Baby tracker and smart home security system

Table 2: Sensei's competing products systems and components' weight.

Product System	Functionality	Weight [g]	BOM	% Weight[5]	Weight [g]	EcoInvent Process
A	Baby tracker	43	LCD[6]	50%	21.5	2620: Liquid crystal display, minor components, auxiliaries and assembly effort
			PCBs[7]	30%	12.9	2601: printed wiring board, surface mounted, unspecified, Pb free
			Rubber	20%	8.6	201: Synthetic rubber - RER
B	Smart home security system	550	LCD	60%	330	2620: Liquid crystal display, minor components, auxiliaries and assembly effort
			PCBs	30%	165	2601: printed wiring board, surface mounted, unspecified, Pb free
			ABS Plastic	10%	55	201: acrylonitrile-butadiene-styrene copolymer

The calculations performed in the OpenLCA software, given the numbers in Table 2, produced the following results (Table 3):

Table 3: GWP of the product systems that compete with Sensei.

GWP_{100} [kg CO_2e]	Product system A	Product system B
	3.97	52.62

[5] Percentages about components' ratio within the product system have been assumed.
[6] LCD = Liquid Crystal Display
[7] Printed Circuit Boards= PCBs

1.2.4. Break-even analysis

A breakeven analysis aims at finding out what production point guarantees that costs are offset by benefits.
The breakeven analysis of Sensei will be carried out with respect to the GWP. This means that benefits correspond to the GWP being avoided, whereas cost is represented by the GWP that occurs. The analysis was carried out according to the notation and the methodology introduced in Barletta, Despeisse, and Johansson (2018):

$$eBEP = \frac{FEC}{VEB - VEC} \quad (2)$$

Given that:
e-BEP = Environmental Breakeven Point
FEC=Fixed Environmental Cost
VEB=Variable Environmental Benefit
VEC=Variable Environmental Cost

Environmental Benefits

Variable environmental benefits (VEC): for each unit of Sensei that replaces either product system A or both the use of product system A and product system B, the VEC are respectively:

Table 4: Environmental benefits of Sensei in substituting one or more competing product systems.

GWP_{100} [kg CO_2e]	**Product system A**	**Product system A+B[8]**	**Product system B**
	3.97	28.29	52.62

Environmental Costs

The Fixed Environmental Costs (FEC) are equal to the sum of:

"Sunk" GWP values from the production and transport of the injection moulding machine
+ Electricity costs for lighting, HCVA and computers in the production facility.

[8] Assumption of 50% use time dedicated to baby monitoring and 50% use time dedicated to home security.

The two members of the addition are scenario-sensitive. As a result, the costs related to the SSP case will be labelled in Table 5 with FEC_{SSP}, whereas the costs related to the MP case will be labelled with FEC_{MP}

Table 5: Fixed environmental costs per volume scenario, in the 3-year lifetime of Sensei.

Fixed Environmental Cost **GWP_{100} [kg CO_2e]**	**FEC_{SSP}**	**FEC_{MP}**
Injection moulding machine: production phase and transportation phase	1.62E+04	0.27E+05
Overhead production facility (lighting, computers, etc.)	4.01E+04	3.00E+05
Total	**5.63E+04**	**3.27E+05**

Table 6 illustrates the environmental costs that vary per unit of Sensei being produced. The only difference between variable costs for the SPP scenario and the MP scenario is the transportations management, whose cost has been allocated per unit of product. The remaining part of the cost are uniquely associated with a unit of Sensei, irrespective of the production volumes.

Table 6: Variable environmental costs per volume scenario.

Variable Environmental Cost **GWP_{100} [kg CO_2e]**	**VEC_{SSP}**	**VEC_{MP}**
Injection moulding process	0.11	0.11
PC/ABS production	0.21	0.21
Transportations	0.44	0.12
Use	1.2	1.2
End of Life	1	1
Total	**2.94**	**2.53**

Environmental Breakeven

Given the costs and benefits' structure, it is evident that there are six environmental breakeven points for Sensei, emerging from the combinations of six attributes:

- Volume scenario (SSP vs MP) (2 attributes)
- Competitiveness of Sensei (substitution of product system A only, substitution of product system A and B simultaneously, and substitution of product system B) (3 attributes).

By using Equation 2 with the appropriate values reported in Table 1 to Table 6, the following breakeven points for Sensei's production have been calculated and reported in Table 7.

Table 7: Environmental breakeven of Sensei in different volume scenarios and competitiveness scenarios

Sensei's environmental breakeven point **e-BEP [units]**	**Substitution Product System A**	**Substitution Product System A+B**	**Substitution Product System B**
SSP scenario	54928	2219	**1132**
MP scenario	**227350**	12708	6537

The values in Table 7 mirror the expectations of:

- A decreasing value of the breakeven point "from left to right" (value for substitution of product system A < value for substitution of product system A +B < value for substitution of product system B)
- Ease in reaching the breakeven when less intensive-capital assets (usually carrying a higher environmental burden), with the assumption that the produced product is actually sold and used.
- The difference between relative numbers (individual GWP values of Sensei in the two volume scenarios, which showed a lower GWP for the MP scenario in comparison to the SSP scenario) and systems-thinking considerations that account for cost structures and market dynamics (turning the SSP scenario with substitution of product system B the favourite outcome environmentally wise).

Figure 7 and Figure 8 graphically illustrate how the breakeven points result from costs and benefits functions for the case of SSP. Since the magnitude between the e-BEP for replacing Product System A and Product System A+B is one size smaller than the e-BEP for replacing Product System B, the graph in Figure 8 displays the e-BEP reached when replacing Product System A and Product System A+B solely.

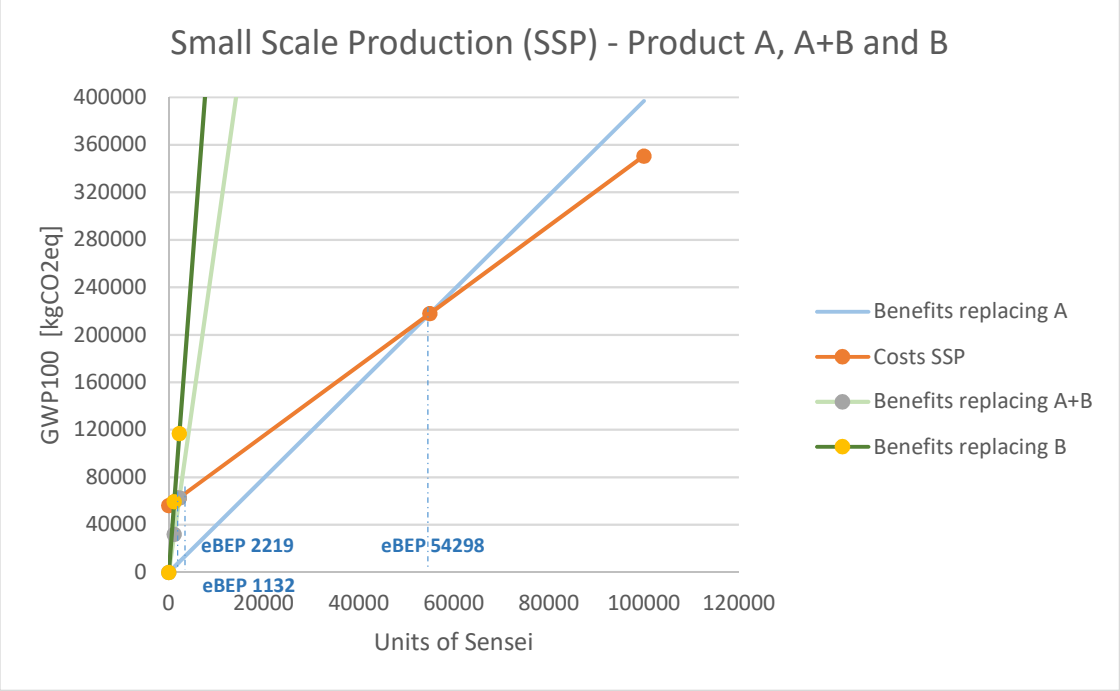


Figure 7: Environmental breakeven points for SSP scenario

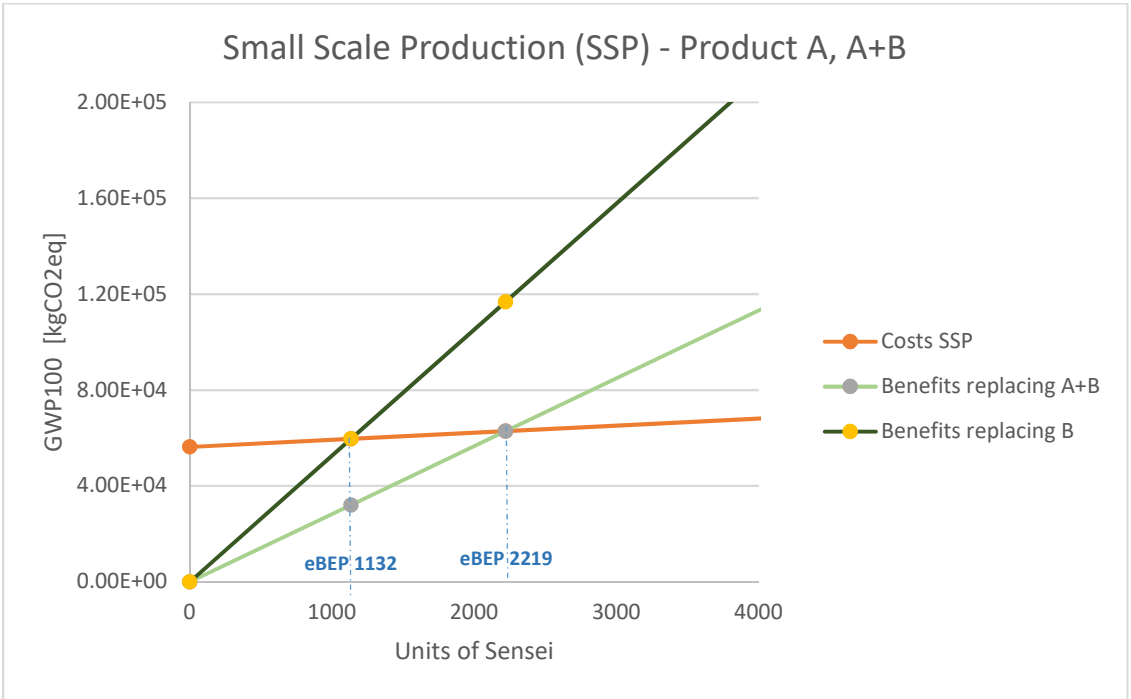


Figure 8: Environmental breakeven points for SSP scenario, substitution of Product A and Product A+B only.

To conclude:

- When focusing on the most favourable breakeven point of 1132 units and considering the SSP volume scenario of a minimum of 2000 units/year being sold: Sensei would pay off its environmental burden after its first half of the year on the market, and start adding environmental benefits starting from the 1133rd unit being sold.

- When focusing on the least favourable breakeven point of 227350 units and considering the MP volume scenario of a maximum of 80000 units/year being sold: Sensei would pay off its environmental burden as it is about to end its second years of sells (2.8 years), and would start adding environmental benefits starting from the 227351th unit being sold.

Due to a lack of granular data about human toxicity potential pertaining specific life cycle stages of Sensei, of the product system A and B, the breakeven analysis will be carried out for the GWP only. However, an analyst who would like to calculate the breakeven from a human toxicity perspective, and has the data to do so, can follow the same method being adopted in this report and prescribed in Barletta, Despeisse, and Johansson (2018).

2. Feasibility of the business model

2.1. Product costs

Considerations about product design and production effort in producing Sensei led to the following industrial costs (Table 8).

Table 8: Product and production cost per a unit of Sensei. Data provided by Boid for the most.

Cost Item	**Price [SEK]**	**Weight [kg]**	**Comment**
Tooling plastic	23	N/A	Calculated on 15 000 products (one time cost 275 000)
Production Plastic parts	75	0.1	Material: http://www.openminddevelopments.com/flaxstic/
Cell phone	0	N/A	Only use phones that Sony deems not re-usable as phones. Phones that today would go to material recycling.
– LED lights	10	N/A	
– Aluminum frame	50	0.03	Used for mounting phone PCB and other components
– Elastic chords	5	0.030	
– USB chord	20	N/A	
– Packaging	40	N/A	
Total	223		
Labour cost		**Time [h]**	**Comment**
Disassembly of phone	N/A	N/A	
Mounting of PCB in plastic covers	N/A	N/A	
Installing software	N/A	N/A	
Packing and transportation	N/A	N/A	
Total range of activities		1.25	
Average hourly labour cost in Sweden	445		Time estimated for the sum of all the activities aforementioned. This time may be reduced to 0.5 h as economies of scale and efficiency progress.
Total	445		
Total	**780**		

Management costs have not been accounted, as unknown so far. A range of sell price has been established among the project partners: it may range from 1000 SEK to 2500 SEK. This means that a preliminary value of the contribution margin[9] ranges from 220 SEK to 1720 SEK.
However, this preliminary contribution margin does not tell how profitable the whole investment in Sensei is, as other costs need to be accounted:

- Software development (e.g., smartphone app development and software installed in Sensei)
- Software maintenance (e.g., fixing bugs)
- Customer service
- Special training of the assembly operators
- Offline marketing campaign (e.g., in stores)
- Digital marketing (e.g., online ads)
- Amortization of the investment
- Possibility to be funded by start-up incubators.

Moreover, the profitability of the investments and the economic breakeven depend not only on the extent but also on the structure of each of the aforementioned costs. Some of them may be fixed, whereas others might be both fixed and variable.

2.2. Existing Barriers and Potential for Sensei's business model success

Barrier #1: No updates on the WEEE Directive in the aftermath of European "circular economy" reformation

The new rules – based on Commission's proposals part of the Circular Economy package presented in December 2015 – will help to prevent waste in the following ways: phasing out landfilling and promoting the use of economic instruments, such as Extended Producer Responsibility schemes "thus making the circular economy a reality" (IMPEL 2018). To date, the WEEE Directive does not appear to be affected by such a "circular economy reformation" positively.

> Potential Solution #1*:* Including targets related to the effectiveness and rapidity in scaling up the waste hierarchy and focusing on systemic environmental burden avoidance.

[9] The contribution margin being calculated here is not the definitive one, as management costs need to be included in the calculation and have not been included yet.

Barrier#2: WEEE Directive still focused on recycling targets (that are also difficult to meet)

Geyer and Doctori Blass (2010) argued that meeting the recycling targets already set by the WEEE Directive is already difficult at the present stage. "Meeting the 65% of mass recycling target would require additional disassembly and separation steps and most likely even redesign of the handset. This is unlikely to happen, however, since requirements of the WEEE directive apply to equipment categories as a whole and not to individual product types like cell phones. Since cell phones make up only a small fraction of category 3 WEEE, it will be much more cost effective to focus product and process redesign efforts on other (bulkier) category 3 products like computers". The author of this report proposes the following solutions:

> Potential Solution #2: Ease the product's segregation from waste streams and product disassembly for better end-of-life processes. An example to achieve that is implementing eco-design practices at the early lifecycle stage of the product.
>
> Potential Solution #3: Granular statistics per type of ICT product. Differentiating mobile phones from other ICT products.

The investigation carried out by Whalen, Milios, and Nussholz (2018) cast a light on several barriers and the potentials for reuse strategies in the Swedish ICT sector.

One of the barriers investigated in the study which is more relevant for Sensei's business model is related to the issue that take-back schemes face:

Barrier#3: High uncertainty in product quality and product volumes from take-back schemes

"…Product quality is not guaranteed and many organizations face low quality products in return (Ongondo, Williams, and Cherrett 2011). Therefore, both lack of access to used products and poor quality of supply can contribute to a lack of sufficient volumes" (Whalen, Milios, and Nussholz 2018).

The following solutions that would weaken barrier #3 have been retrieved again from Whalen, Milios, and Nussholz (2018)

> Potential Solution #4: "More information to citizens that reuse of ICT is good for the economy and environment"
>
> Potential Solution #5: "Receive more information about the functionality from the previous user"
>
> Potential Solution #6: "More ambitious targets and progressive use of public procurement in the public sector to promote reuse of goods"

To conclude, a set of recommendations to producers of products like Sensei, smartphone manufacturers and regulators are given. These recommendation stem uniquely from what has been learned in the project's case study and existing.

Recommendations to Sensei's producer and producers of similar products alike:

Reducing the environmental impact of the product by:

- Acquiring less material-intensive machinery (e.g., additive manufacturing would be proper for a small-scale and low volume scenario)
- Acquiring used machinery (e.g., injection moulding machine) as a result of an extended life-time strategy
- Optimizing shipping routes for deliveries to customers
- Sizing the production facility after getting an accurate market analysis that validates the business model. An oversized production facility would make product's economic and environmental costs skyrocket.
- Communicating the environmental performance of the product in order to increase the customer base, made up of environmentally conscious customers.

Recommendations to smartphones' manufacturers:

- Increased collaboration between electronics producers in order to promote industrial symbiosis when demands for different products balance out and when they share similar components
- Increased compliance with product responsibilities and visualization of statistics to auditors and customers for increased transparency
- Avoiding product models' overproduction and eliminating the reason to come up with a "spare" product like Sensei, irrespective of its usefulness and environmental benefits it provides at some point.

Recommendations to governments and environmental regulators:

- Governments under the WEEE Directive can help producers tracking their progress towards higher and higher sustainability performance by providing them with tools to:
    - track statistics about product buy backs
    - have visibility of the effectiveness of end of life strategies from an economic and environmental perspective.

References

Barletta, I., M. Despeisse, and B. Johansson. 2018. 'The Proposal of an Environmental Break-Even Point as Assessment Method of Product-Service Systems for Circular Economy', *Procedia CIRP*, 72: 720-25.

Ercan, Elif Mine. 2013. "Global Warming Potential of a Smartphone Using Life Cycle Assessment Methodology." In, 62. Stockholm: KTH.

Ercan, Mine, Jens Malmodin, Pernilla Bergmark, Emma Kimfalk, and Ellinor Nilsson. 2016. "Life cycle assessment of a smartphone." In *4th International Conference on ICT for Sustainability (ICT4S 2016)*.

Geyer, Roland, and Vered Doctori Blass. 2010. 'The economics of cell phone reuse and recycling', *The International Journal of Advanced Manufacturing Technology*, 47: 515-25.

IMPEL. 2018. "Circular Economy: New rules will make EU the global front-runner in waste management and recycling." In, edited by European Union Network for the Implementation and Enforcement of Environmental Law.

ISO14044:2006. 2006. "Environmental management -- Life cycle assessment -- Requirements and guidelines." In.

Menezes, A. C., A. Cripps, R. A. Buswell, J. Wright, and D. Bouchlaghem. 2014. 'Estimating the energy consumption and power demand of small power equipment in office buildings', *Energy and Buildings*, 75: 199-209.

Ongondo, F. O., I. D. Williams, and T. J. Cherrett. 2011. 'How are WEEE doing? A global review of the management of electrical and electronic wastes', *Waste Manage.*, 31: 714-30.

Pré. 'ReCiPe', Accessed October 17 2018. https://www.pre-sustainability.com/recipe.

Røyne, Frida, and Johanna Berlin. 2018. "The importance of including service life in the climate impact comparison of bioplastics and fossil-based plastics." In.

Verlag, Carl Hanser. 2015. "The Carbon Footprint of an Injection Molding Machine." In *Kunststoffe international*, 47-50. Munich, Germany: Hanser Publishers.

Whalen, Katherine A., Leonidas Milios, and Julia Nussholz. 2018. 'Bridging the gap: Barriers and potential for scaling reuse practices in the Swedish ICT sector', *Resources, Conservation and Recycling*, 135: 123-31.

Appendix A

Product data

Sensei's bill of material. Data provided by Boid.

Table 9: Bill of material of Sensei.

BOM	Component	Material	Weight [g]
Main component #1	Mobile Phone	Mix	150
Main component #2	Plastic cover	PC-ABS	100
Total			250

Sensei's usage parameters. Data provided by Boid.

Table 10: Usage parameters of Sensei.

Usage Parameter	Amount
Estimated life time	2-4 years
Power	0.5 W

As average scenario, a life span of 3 years has been modelled in the analysis.

Appendix B

Environmental analysis – Data and methodological approach[10]

Table 11: Estimated Global Warming Potential (GWP) of Sensei per life cycle stage in an average 3-year lifetime..

GWP_{100} [kg CO_2e]	Case production	Assembly	Transportation	Use	End of Life	**Total**
SSP scenario *min 2000 units/year*	3.02	6.68	0.44	1.2	1	**12.3**
MP scenario *80000 units max/year*	0.43	1.25	0.13	1.2	1	**3.98**

Case production

Recycled PC-ABS (case's material):

The GWP from the production of the recycled PC/ABS has been retrieved from Røyne and Berlin (2018), with the hypothesis of a ratio of 50% PC and 50% ABS and a recycling rate of virgin material 60%. The environmental impact of the PC/ABS recycling process was not found in either the Ecoinvent database nor in the scientific literature, and therefore not accounted. This also motivated the choice of a conservative recovery rate of the PC/ABS, rather than the choice of a recovery rate higher than 60%, which would have been more realistic. The resulting GWP per unit of Sensei in a 3-year lifetime is:

GWP_{100} [kg CO_2e]	0.21

Injection moulding process:

The impact of the case production via injection moulding has been calculated through the process in Ecoinvent "injection moulding – RER" of 100.6036 g of material (considering 0.6% of waste). The life cycle impact assessment method (LCIA) being used is ReCiPe (Hierarchist[11]) Midpoint (Pré). The resulting GWP per unit of Sensei in a 3-year lifetime is:

[10] Calculation sheets are available on request. Email ilaria.barletta@chalmers.se

[11] Hierarchist: "Consensus model, as often encountered in scientific models, this is often considered to be the default model" (Pré).

GWP_{100} [kg CO_2e]	0.11004

Injection moulding machine:

The environmental impact of building the injection moulding machine has been retrieved from Verlag (2015). Given the massive size of the injection moulding machine (a KraussMaffei GX550-4300) which was object of the LCA, its value of GWP (81 t CO_2e excluding the injection moulding process in the use phase) have been downsized to 1/5[12] for the case of SSP and to 1/3[13] for the case of MP. This led to a GWP of 16.2 t CO_2e for the case of SSP and 27 t CO_2e for the case of MP.

The resulting GWP per unit of Sensei in a 3-year lifetime is:

GWP_{100} [kg CO_2e]	**SSP scenario**	**MP scenario**
	2.7	0.1125

Although the impact from the production and transport of the injection moulding machine has been allocated to the units of Sensei, the value of a GWP of 16.2 t CO_2e for the case of SSP and 27 t CO_2e for the case of MP are to be considered fixed environmental costs. This is important to consider when calculating the environmental breakeven of Sensei. It is evident that the environmental impact of Sensei's case production can be reduced drastically if the machinery equipment is purchased by Sensei's manufacturer from another company that had previously used the machine and would want to extend its end of life.

Assembly

It is assumed that Sensei is produced in an already existing facility and in a formerly spared area of it now dedicated to Sensei. This scenario is at odds with the one, more "polluting" and less likely, of building a new facility from scratch for the sole purpose of Sensei.

The variable environmental cost of the assembly operations as such can be considered negligible, being it manual.

Fixed environmental costs related to electricity supply, heating, ventilation, and air conditioning (HVAC) of the production facility have been accounted in the environmental break-even analysis at page 15. This also applies to the impact from the use of computers, that are assumed to be used for software installations, testing, managing orders, etc.

The hypotheses have been formulated have been marked with (ʘ) in the table below:

[12] Sensitive assumption.

[13] Sensitive assumption.

Table 12: Sensei's production parameters and variables.

Sensei's production	Source	SSP scenario	MP scenario
Area of the production facility ɵ	N\A	300 m^2	800 m^2
Facility working time ɵ	N\A	8 hours a day, 1 shift per day	12 hours a day, 2 shifts per day
Power load density for lighting, HVCA, computers	10 W/m^2 (Menezes et al. 2014)[14]		
Area of the production facility where equipment for lighting, HVCA, and computers are placed ɵ		10	25
Facility's energy consumption (3[15] years)		600 MWh	4500 MWh
GWP100, SWE electricity, low voltage 3 years for entire facility	Ecoinvent database and OpenLCA	4.01E+04	3E+05

Given the volume scenarios for SSP and MP, the resulting GWP per unit of Sensei in a 3-year lifetime is:

GWP_{100} [kg CO_2e]	SSP scenario	MP scenario
	6.68	1.25

Semi-fixed (or, from a different perspective, semi-variable) environmental costs exist, like the ones caused by workers' commute to and from the facility[16]. Given the unknown characteristics of Sensei's production (e.g., the specific location in Sweden, the size of the work force needed), the commuting costs have been excluded from the analyses, although they should be included as soon as data is available.

[14] Menezes et al. (2014) estimated the energy consumption and power demand of small power equipment in office buildings. The parameter being chosen as power load density is related to the profile "Naturally ventilated cellular office" + "Good Practice".

[15] Average lifetime of Sensei.

[16] Although they would be accounted within the "pool" of transportations' impact, the commuting environmental costs are still triggered by the assembly stage.

Use

A use occurring 24/7 for 3 years has been modelled. This is a realistic scenario for the case of using Sensei as opposed to a home security alarm. Swedish district heating has a GWP of about 90g of CO_2e/kWh. The resulting GWP per unit of Sensei is:

GWP_{100} [kg CO_2e]	0.12

Transportation

Table 13: Transportations parameters and variables.

Travel distances	Source	SSP scenario	MP scenario
Components to assembly facility	N\A	300 km	300 km
From assembly facility to customers		300 km	400[17] km
To end-of-life facility		300 km	300 km
Carrier	Ecoinvent	Freight, light commercial vehicle	Freight, lorry, 3-5 – 7.5 metric ton, EURO5 - RER

After running the calculations in the OpenLCA software, the resulting GWP per unit of Sensei in a 3-year lifetime is:

GWP_{100} [kg CO_2e]	**SSP scenario**	**MP scenario**
	0.44	0.13

End of life

After its lifetime, Sensei's end of life follows the recycling path prescribed by the WEEE Directive. Because of this, the GWP of the end of life phase can be considered roughly the same of the one of a Sony Xperia™ in Ercan (2013). In fact, disassembly and recycling operations should not differ significantly between the ones applied to a smartphone and to Sensei, given that the difference in weight between the smartphone and Sensei does not affect the prescribed end-of-life recycling processes significantly.

GWP_{100} [kg CO_2e]	1

[17] A longer distance from the assembly facility to the customer has been assumed for the MP scenario. It is reasonable to assume that shipping to "more disperse" customers in the Swedish territory would happen in the MP scenario.

Note: as illustrated in WP2 deliverables, the studies that have been selected for retrieving values of global warming potentials of a representative smartphone for Sensei's case are Ercan (2013) and (Ercan et al. 2016), as the functional unit of the study was one Sony Xperia™ T. Both the studies used Gabi software as modelling tool for LCA, data sets from Ecoinvent and Gabi's data itself.