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Life Cycle Analysis of a Microtech-process

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1 Summary

The conducted life cycle assessment (LCA) is part of the first loop of the “NTN Innovation Booster – Microtech” program and aims at answering the following research question:

Are datasets of standard processes in existing databases valid to depict corresponding microtechnology processes?

The environmental impacts from an industrial process were computed using datasets from an LCA database and specific data from the microtech sector. The comparison of the impacts from datasets available in the LCA database ecoinvent (standard and standard-modified scenarios) and from specific microtech (microtech scenario) data was used to investigate the research question. For the analysis, the manufacturing of two watch components, an axis and a wheel, was assessed.

The analysed manufacturing process contains seven steps, that take place both in the machine manufacturing sector producing ‘average scale parts’ (referred to as ‘standard’ in this report) and in the microtech sector. The seven sub-processes are:

1. **Turning**: Shaping the general geometry of the metal piece
2. **Washing 1** (degreasing): Degreasing, cleaning impurities
3. **Hardening**: Setting wanted material properties like hardness
4. **Washing 2**: Cleaning impurities (solvent, oil, etc.)
5. **Tempering**: Balancing toughness and hardness
6. **Polishing:** Treating the roughness
7. **Washing 3**: Getting rid of impurities

The assessed LCA database contains data for the sub-processes turning, washing 1, 2 and 3 and tempering. No corresponding datasets were found for hardening and polishing.

The comparative assessment was made using two life cycle impact assessment methods:

- Global Warming Potential 100 (GWP100) → Results in kg CO_2-eq.
- Ecological scarcity method 2013 → Results in Eco-points (UBP)

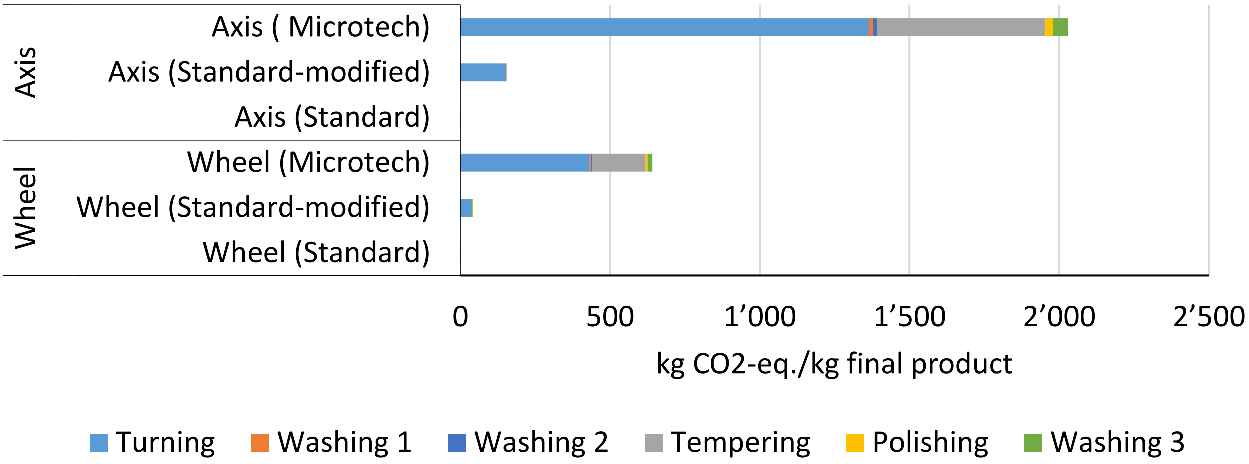


Figure 1: LCA results in kg CO_2-eq.

The main findings of the study are:

- The microtech processes analysed generate substantially higher environmental impacts than standard scale industrial processes per kg of material processed (up to a factor of 9 and more)
- Turning**:** The electricity demand seems to be underestimated with standard values
- Washing: The electricity and the solvent have the highest impacts in the microtech scenario
- Tempering: Both the forming gas and the energy consumption are underestimated with the standard dataset

These findings lead to the following recommendations:

- ➢ The datasets provided in the LCA database ecoinvent are not suited to assess the environmental impacts of the analyzed watch component manufacturing process (and probably other similar manufacturing processes within the microtech sector)
- ➢ Specific datasets for microtech processes should be developed
- ➢ Future analyses should assess the representativeness of the watch manufacturing sector for other microtech sectors, parallel to the development of microtech-specific life cycle inventories

2 Introduction

2.1 Project context

The present study is a project part of the first loop of the "NTN Innovation Booster – Microtech" program and was launched by Gaylord de Lamarlière, owner of the engineering company "109 Degrés" in Neuchatel, Switzerland.

2.2 Research question

The overall goal of this study is to help towards answering the following research question:

Are datasets of standard processes in existing databases valid to depict corresponding microtechnology processes?

Microtechnology enables the realisation of manufacturing processes with a precision within the order of a micrometre and products in the size order of a few millimetres. In this report, the terms "microtechnology" and "microtech" refer to the same sector. In the present report, the term "standard processes" describes industrial processes that handle technology components with a scale larger than a few millimetres.

A microtechnological process in the watch manufacturing sector and the corresponding standard process are compared with the help of a comparative life cycle assessment (LCA) to find an answer to the research question.

2.2.1 Sub-goals

The main objective of this comparison is to evaluate the representativeness of existing standard process data in LCA databases for a microtechnological application. The comparison and the evaluation of the representativeness should take the following elements into account:

1. Sub-processes that are part of the main process
2. Functional unit choice
3. Results of the conducted LCA with chosen impact assessment methods

3 Methodology

3.1 Life Cycle Assessment (LCA)

The present LCA complies with the structure described in the ISO 14040 (Figure 2). This structure is based on the following elements:

Goal and scope

The goal and scope definition determines the system boundaries and the purpose of the conducted LCA. The functions, uses and benefits of the analysed system are set within the goal and scope definition, as well as assumptions and limitations of the study.

Life Cycle Inventory (LCI)

Data for the material and energy flows within the considered system boundaries are compiled in the life cycle inventory (LCI). The LCI contains two levels of data: foreground and background data. Foreground data depict the main material and energy flows, for instance the electricity and raw material consumptions, the amount of waste, etc. Background data describe the material and energy flows that take place for instance during the production phase of considered raw materials.

In the present study, watch manufacturing experts provided all foreground data for the microtech-process. For the background and foreground data for the standard process, as well as for the background data for the microtech process, data from the ecoinvent database are used.

Life Cycle Impact Assessment (LCIA)

Environmental impacts are calculated based on the set system boundaries and the computed LCI. This step contains an implicit evaluation, which is due to the choice of the impact assessment method and the considered impact categories. Two impact assessment methods are applied in this study:

- Global Warming Potential 100 (GWP100)
- Ecological scarcity method 2013

Interpretation and discussion

The result of the steps above are interpreted and discussed in a last step. A sensitivity analysis can also be conducted in order to validate the results of the study and identify relevant parameters.

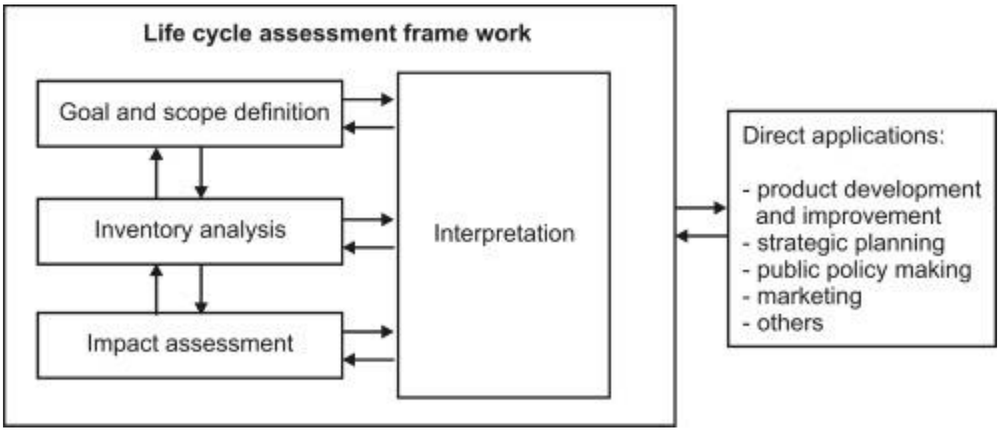


Figure 2: LCA phases based on DIN EN ISO 14040:2006 (Source: sciencedirect.com, accessed on the 3rd of January 2022)

3.1.1 Database

The reference LCA-database in this project is ecoinvent v. 3.6. Ecoinvent is a non-proft based association based in Zürich, Switzerland. The aim of the organization is the development of a consistent database for sustainability assessment. The main focus of the association is the compilation, linking and distribution of worldwide LCI data. The database has been in place for more than 20 years and contains more than 19'000 reliable LCI datasets. It is in constant evolution and regularly updated. The association is also involved in different projects worldwide that enhance good practices in the creation and use of LCI data. The data can be accessed through different licenses and is available in different formats.

3.1.2 Impact assessment methods

Impact assessment methods are needed to quantify and aggregate the environmental impacts of both the standard and microtech processes. Two impact assessment methods were chosen:

3.1.2.1 Global Warming Potential 100 (GWP100)

The global warming potential is a measure for the total amount of direct and indirect CO_2 emissions out of activities of company sites, products or individuals during their life cycle. Other greenhouse gases than CO_2 are taken into account in form of CO_2-equivalents (CO_2-eq.). The method uses factors from the Intergovernmental Panel on Climate Change (IPCC) for the conversion of greenhouse gas emissions to CO_2-eq. emissions. In the present work, a standard time horizon of 100 years is considered.

3.1.2.2 Ecological scarcity method 2013

The Ecological Scarcity 2013 method aggregates the results in one score, rendered in so called Eco-points (UBP, from the German word "Umweltbelastungspunkte", which means "environmental impact points"). This method links the life cycle inventory results (emissions, resources used, wastes, etc.) to Eco-points via a characterization (primary energy, ozone depletion potential, biodiversity damage potential, etc.). The characterization is based on the legislation or corresponding policy goals and current pressure situations. The Eco-points are computed based on the difference between the calculated emissions or resource use and the environmental target. A higher exceedance of the target leads to a stronger impact weight of the considered emission or material use.

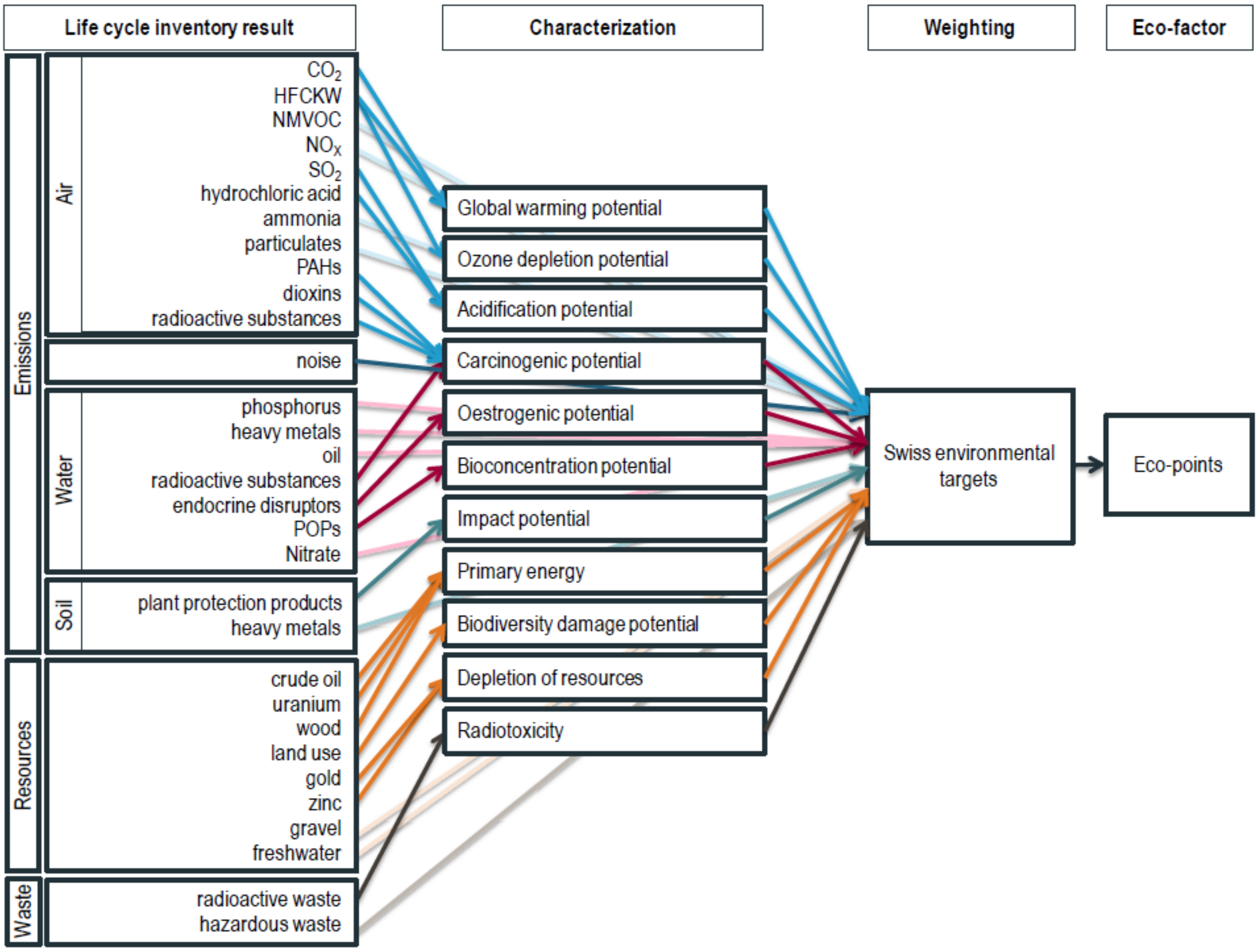


Figure 3: Structure of the Ecological scarcity method 2013 (Source: bafu.dmin.ch, accessed on the 11th of January 2022)

3.2 Reference process

For the planned comparison of a standard and a microtech process, the manufacturing of two watch components, an axis and a wheel, was chosen as reference process. This process involves turning, which is a machining process that is used to shape metal pieces by removing material from a rotating object and finds application in a variety of technologies: cars, planes, phones, etc. In watch manufacturing, bar turning is used to shape watch components like wheels pinions, and all cylindrical parts that are then either parts of the watch movement or the watch casing. The reference process in the watch manufacture is composed of seven sub-processes:

1. **Turning**: Shaping the general geometry of the metal piece
2. **Washing 1** (degreasing): Degreasing, cleaning impurities
3. **Hardening**: Setting wanted material properties like hardness
4. **Washing 2**: Cleaning impurities (solvent, oil, etc.)
5. **Tempering**: Balancing toughness and hardness
6. **Polishing:** Treating the roughness
7. **Washing 3:** Getting rid of impurities

The considered production process in the watch manufacturing sector (microtech process) is shown in Figure 4. It is important to note that in this figure, polishing and washing 3 are represented as one process. The two are split into two distinct sub-processes in the model.

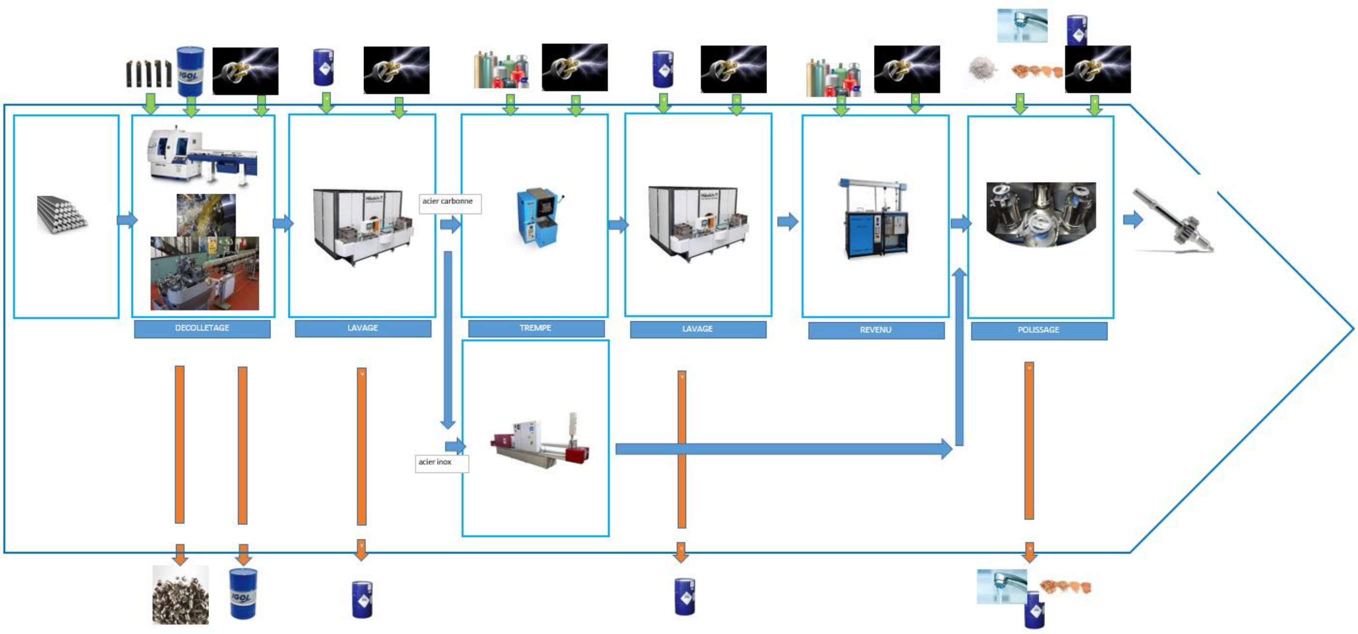


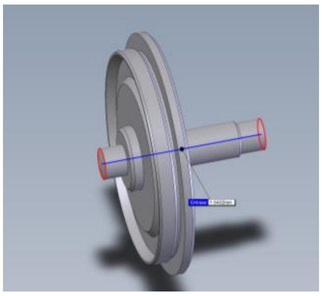
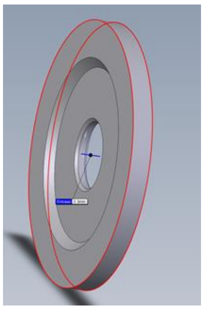
Figure 4: Reference process involving bar turning in watch manufacturing

3.3 Reference products

Two reference products were chosen for the study. For each one of these, a comparison between the modelling with existing data (standard scenario and standard-modified scenario for the turning sub-process) and the one with specific data (microtech scenario) is conducted.

The first reference product is an axis made of steel, with a weight of 0.0036 g and a surface of 11.87 mm^2. The second product is a steel wheel which has a simpler shape and a different form factor than the axis, with a weight of 0.0113 g and a surface of 18.94 mm^2. The reference product information is available in Table 1.

Table 1: Main features of the considered reference products

Image		
Reference	4005312	4005289
Name	Axis	Wheel
Weight [g]	0.0036	0.0113
Mass density [g/mm³]	0.0075	0.0075
Max. length [mm]	1.69	0.30
Max. diameter [mm]	2.26	3.48
Surface [mm²]	11.87	18.94
Volume [mm³]	0.46	1.51

4 Results and discussion

4.1 Sub-processes

A database analysis was conducted in order to find appropriate datasets for the modelling of the standard process. In parallel, the LCI data from a Swiss microtech company were collected. The following chapters describe the sub-processes and the main modelling assumptions and approximations. Where this was possible, the background data used for the microtech process was the same one as implemented in the existing datasets (for instance electricity mix, steel production).

4.1.1 Turning

The desired geometry of the metal piece is obtained during this step, it is the main sub-process of the whole considered production process. Ecoinvent includes 18 turning processes for each aluminium, brass, cast iron, chromium steel and steel. The processes vary regarding geographic validity (Global, Europe, Rest of the world), finishing type (primarily dressing or primarily roughing) and the controlling (conventional or computer numerical controlled). The present analysis focuses on steel products and therefore only considers the relevant datasets. On top of that, the machines at the microtech plant are numerically controlled. Because the impacts from the microtech scenario are expected to be higher than those from the standard process computed with existing datasets, a conservative assumption is to choose the existing dataset with the highest specific impacts, which is turning for primarily dressing and with computer numerical controlling. This dataset was chosen for the modelling of the standard turning process.

Efficiency of the turning process

All turning datasets in ecoinvent are based on the amount of metal removed and the value of 0.23 kg of metal removed per kg of shaped product is recommended if no other data is available. This means that 1.23 kg of primary steel is needed for the manufacturing of 1 kg product.

For the reference products chosen, this value amounts to 41.22 kg removed per kg product for the axis and 10.50 kg removed per kg product for the wheel. This means that 42.22 kg and 11.50 kg of steel are needed for the manufacturing of 1 kg of axes, respectively of wheels.

Auxiliary

All existing turning datasets contain an input called “Energy and auxiliary inputs, metal working machine”. This dataset contains in turn four sub-datasets, which only differ on the process heat source. The sources are: light fuel oil, natural gas, hard coal and heavy fuel oil, in decreasing order regarding the quantities. The only difference between these datasets is the amount and the source of process heat energy considered. The computed amount of this dataset is based on the ratio kg removed:kg product and should therefore be adapted for other ratios.

4.1.2 Washing 1 (degreasing)

In this step, the shaped metal piece is cleaned from oil and other impurities. In ecoinvent, a dataset for degreasing metal parts in an alkaline bath is available. The reference for this process is 1 m^2 of degreased metal.

This dataset is the closest that could be found for degreasing metal parts and was therefore implemented into the model. However, it is important to note that it differs from the process at the considered Swiss microtech company, where solvent and no water is used for washing (please refer to appendix 6.1.2 for detailed information).

4.1.3 Hardening

No corresponding dataset could be found in the database. On top of that, the time at disposal to collect and allocate the specific data for this sub-process and the considered reference products at the Swiss microtech was not sufficient. This step, even though part of the reference process, is for time reasons not analysed further in the present study.

4.1.4 Washing 2

Because oil is used in the step prior (hardening), the same dataset as for washing 1 was used, even though the washing technology also differs from the one in place at the Swiss manufacturing plant considered in the study.

4.1.5 Tempering

Several tempering datasets are available in ecoinvent. The most suitable one is named “impact extrusion of steel, cold, tempering” and is valid for Europe. As the name states it, the process data was modelled from the extrusion industry but has the same function as the process used at the Swiss microtech company, namely obtaining the desired balance between roughness and hardness via thermal treatment. The existing dataset refers to the tempered product mass.

4.1.6 Polishing

In ecoinvent, no specific dataset could be found for polishing. The microtech sub-process “polishing” analysed at the microtech company shows that it is made of two sub-processes: polishing and washing. Data from the Swiss company considers polishing and washing 3 as one step. The data for the microtech process is linked to the data of the polishing step and the allocation between the two processes was conducted based on expert knowledge. Similarly to washing 1 and 2, the washing after the polishing step was modelled with the dataset “washing (degreasing)” from ecoinvent, even though the technology slightly differs from the one in place at the Swiss manufacturing plant.

4.2 Functional unit

The choice of the functional unit (FU) is fundamental in an LCA and should guarantee a fair comparison between the products or company sites taken into account. In the present study, two scenarios of the manufacturing process are compared, one scenario using specific data from the microtech sector (watch components manufacturing), the other one data from ecoinvent, involving standard industrial technologies. For the present study, 1 kg of final product was chosen as the FU. This means that the computed environmental impacts always refer to the manufacturing of 1 kg product.

It is important to note that the reference unit of some of the sub-processes in the database are not 1 kg of final product. These datasets were accordingly modified during the modelling, to enable the results to be expressed in reference to the chosen FU.

4.3 Life cycle impact assessment (LCIA)

The following sections display the life cycle impact assessment (LCIA) results in kg CO_2-eq. and in UBP. The data behind the graphs is available in the appendix. For the three sub-processes identified in the database, a comparison of the contribution of each categories within the sub-process (primary materials, expendables, energy, etc.) is also presented.

4.3.1 Overall LCIA

The comparison of the absolute environmental impacts of the scenarios with the two impact assessment methods lead to the following findings:

- Microtech scenario with highest environmental impacts for both references and both impact assessment methods
- CO_2-eq.:
    - Ratio axis Microtech:Standard modified = 13
    - Ratio wheel Microtech:Standard modified = 16
- UBP:
    - Ratio axis Microtech:Standard modified = 9
    - Ratio wheel Microtech:Standard modified = 12

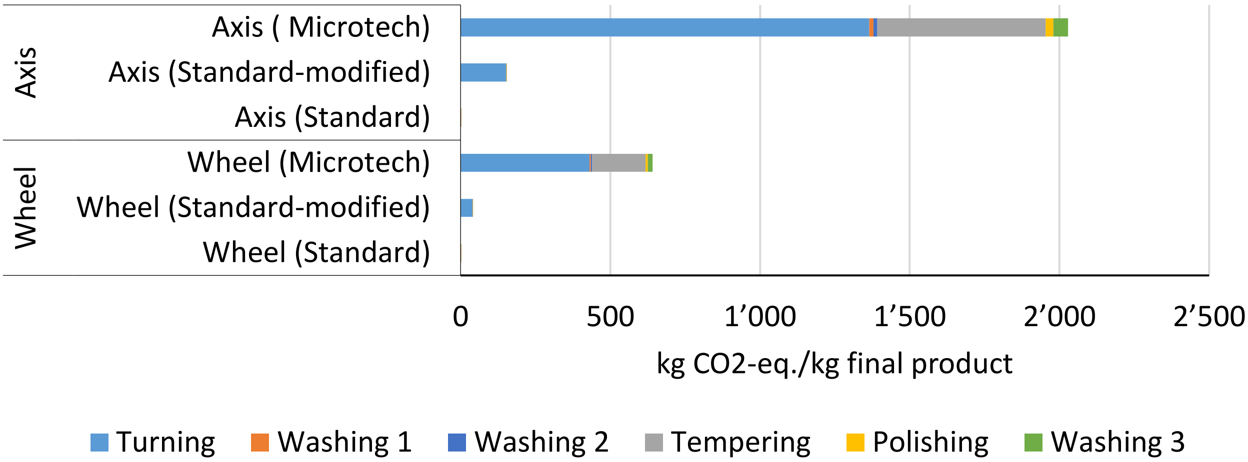


Figure 5: LCA results in kg CO_2-eq. per kg of final product

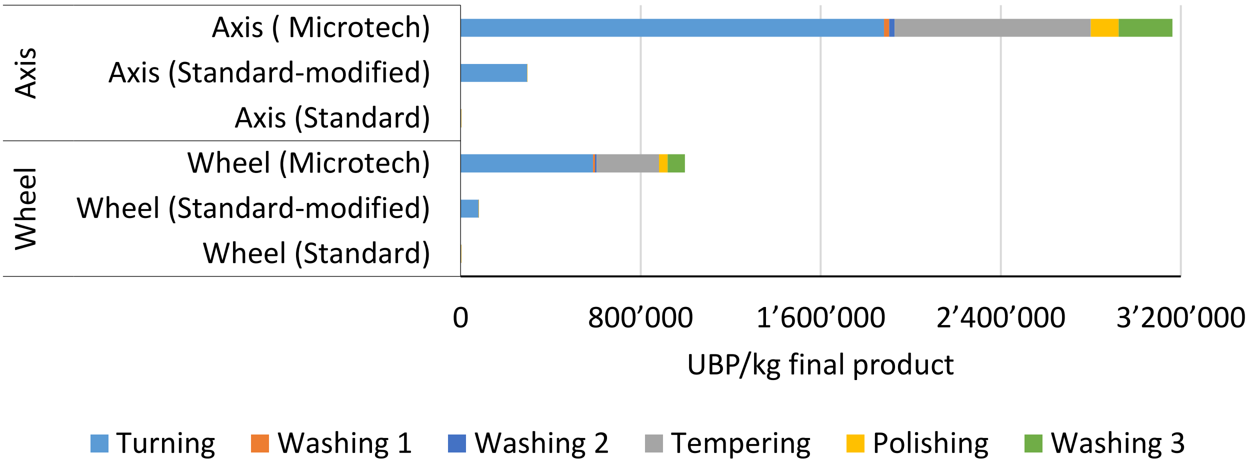


Figure 6: LCA results in UBP per kg of final product

4.3.2 Sub-process LCIA

To understand the underlying differences between the scenarios and the role of each sub-process in the overall LCA, the following graphs show the share of each category analysed within each sub-process.

Turning

- The electricity demand seems to be underestimated with standard values and with both impact assessment methods
- The production of the primary material has a higher relative impact with standard values
- Primary material production has even a higher share with UBP in the standard process
- For each product and impact assessment method, the absolute values of the environmental impacts of steel are the same in the scenarios “Microtech” and “Standard-modified”

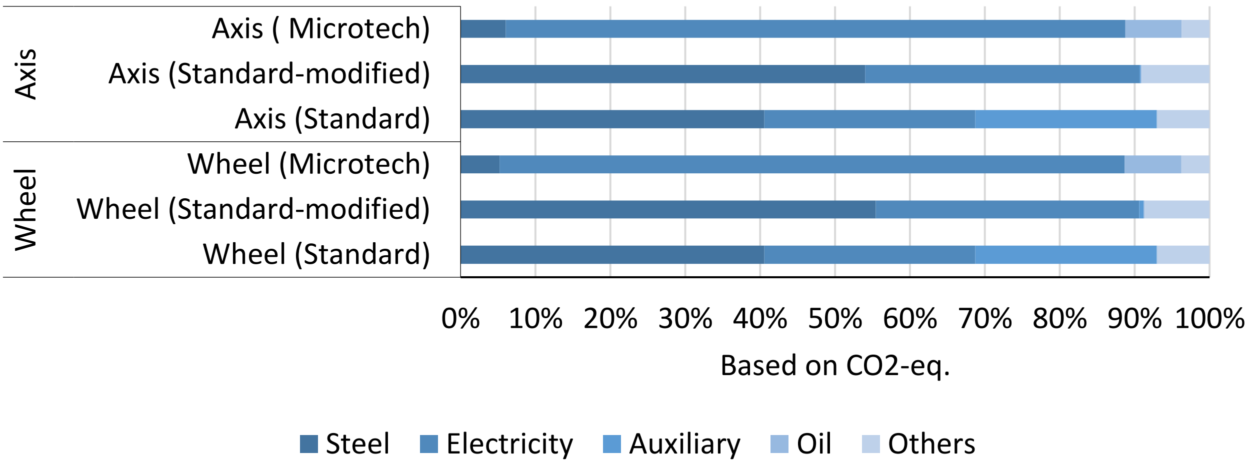


Figure 7: Shares of the different categories in the turning sub-process, based on kg CO_2-eq.

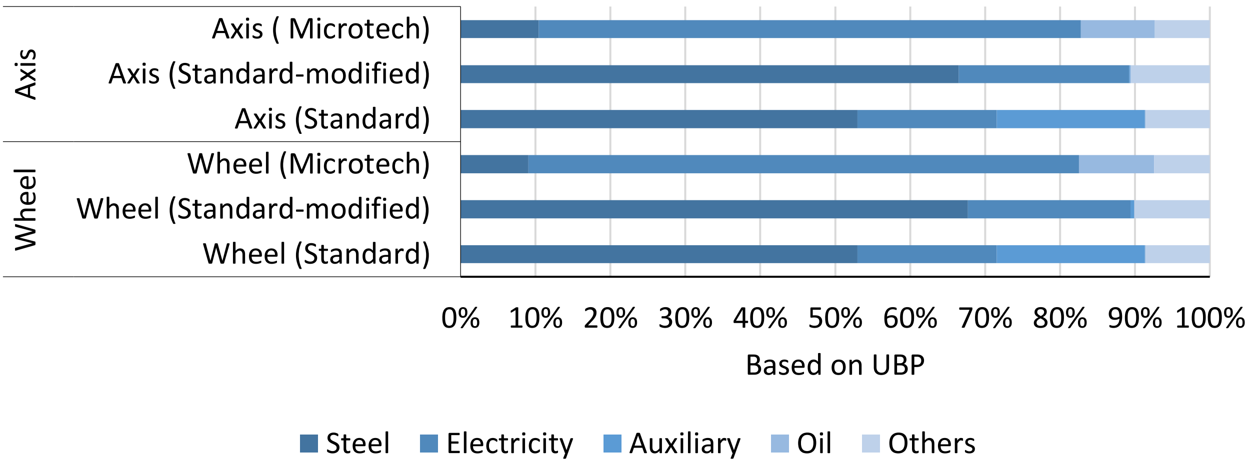


Figure 8: Shares of the different categories in the turning sub-process, based on UBP

Washing

- The electricity and the solvent have the highest impacts in the microtech scenario
- In the existing dataset, the categories “wastewater” and “Others” have the highest share.
- In the category “others”, the consumption of tap water and sodium chloride have the biggest impacts
- In the standard scenario and with the UBP method, the treatment of the wastewater causes the majority of the impacts

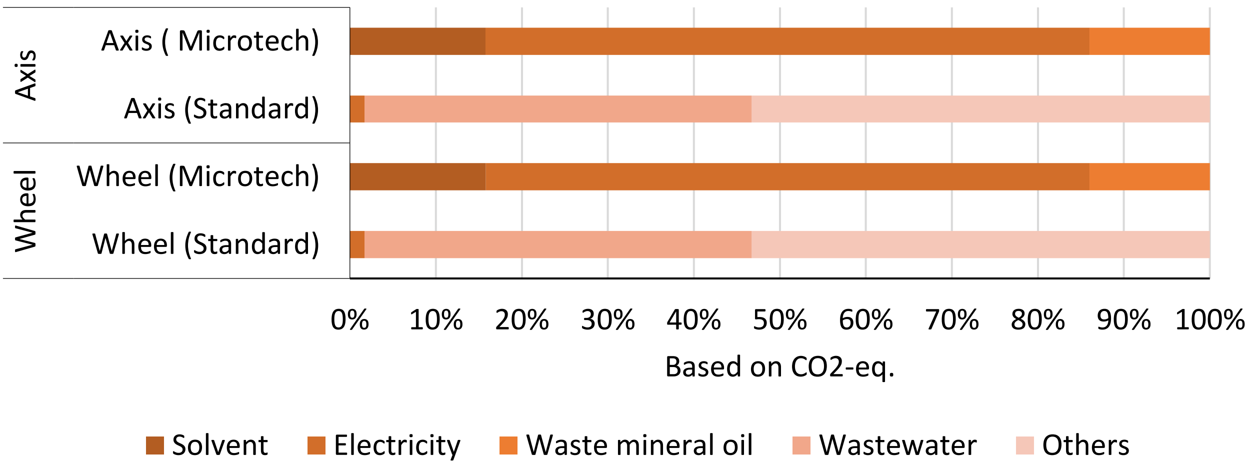


Figure 9: Shares of the different categories in the washing sub-process, based on kg CO_2-eq.

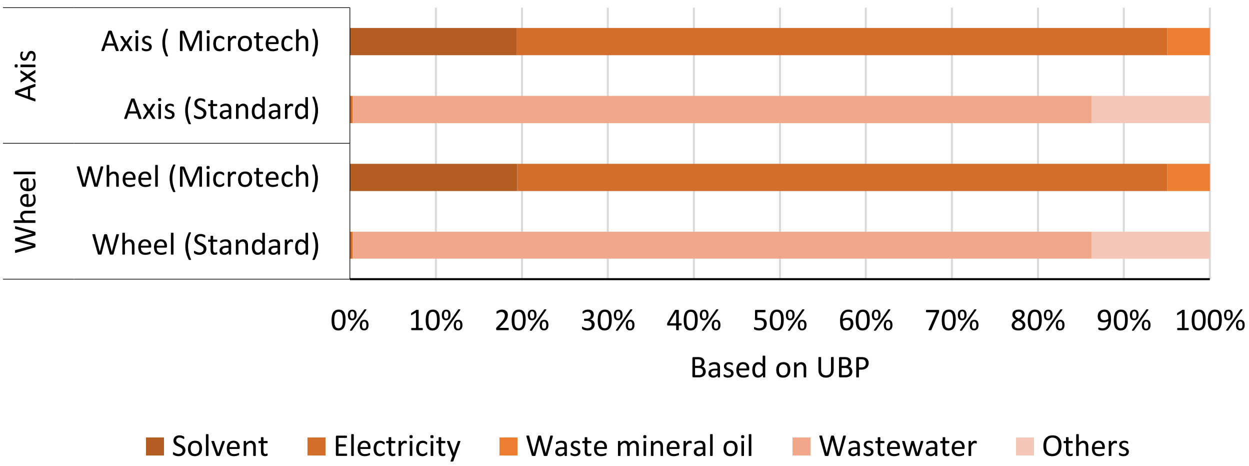


Figure 10: Shares of the different categories in the washing sub-process, based on UBP

Tempering

- Both the forming gas and the energy consumption are underestimated with the standard dataset
- The results are similar with both indicators and for both reference products

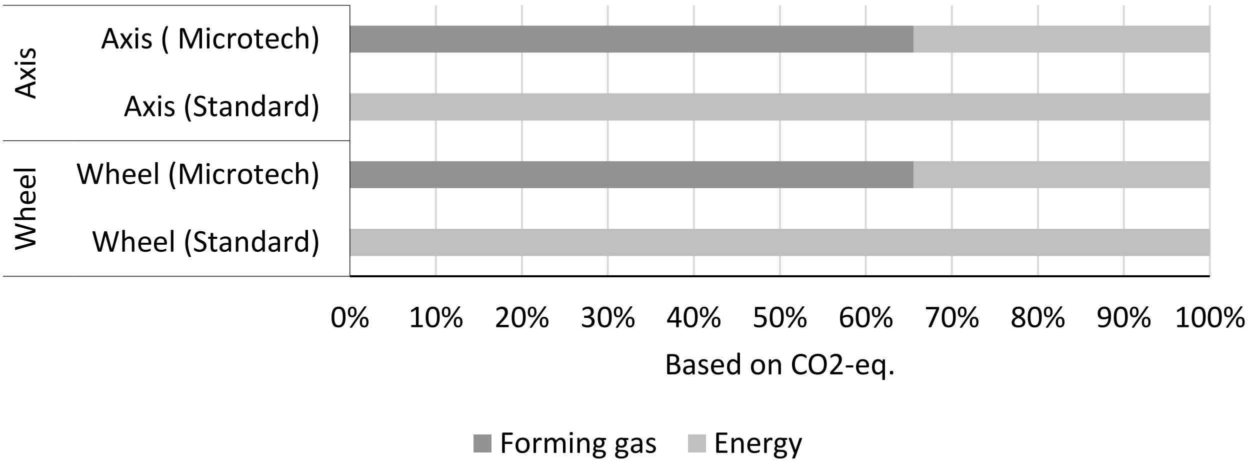


Figure 11: Shares of the different categories in the tempering sub-process, based on kg CO_2-eq.

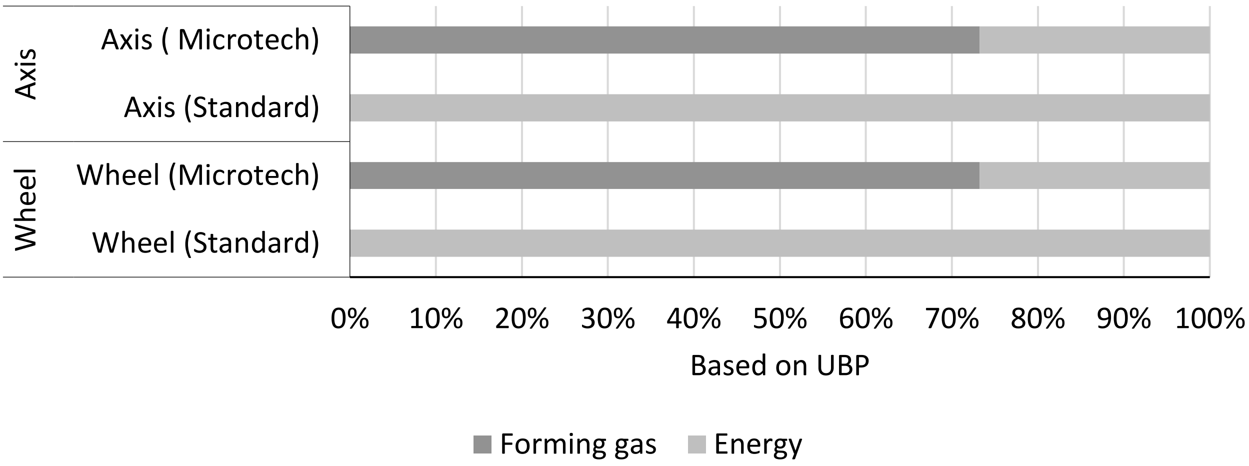


Figure 12: Shares of the different categories in the tempering sub-process, based on UBP

5 Conclusion and recommendations

5.1 Generalisation of the findings

The conducted LCA shows substantial differences between the standard datasets from ecoinvent and those generated with specific data from a Swiss microtech company. As standard ecoinvent data is not representative for microtech processes, it is advised to develop microtech-specific life cycle inventories for LCAs of processes and products in the microtech sector. It is assumed that the present findings, generated from data from the watch manufacturing sector, also apply to other microtech sectors. However, this assumption should be validated through further investigations.

5.2 Validation of existing datasets

Existing datasets could be found for four of the six sub-processes identified. The processes turning, washing 1, 2 and 3 and tempering were modelled for the standard and the microtech scenarios. Polishing was only modelled for the microtech scenario and hardening was not modelled at all.

It is important to note that the modelling purpose of the study is the comparison between standard and microtech processes. The assumptions made and modelling decisions taken might differ from the ones made and taken for a specific company LCA of the considered microtech plant. The steel used in the watch manufacturing sector contains a certain amount of lead for instance and the dataset that was used for steel input in the model doesn't contain exactly the same amount of steel. The same applies for the electricity mix used in the model. Because the focus lays on the comparison, it was important to use the same input data for all scenarios, hence the same electricity mix was used in standard and in microtech scenarios, so that the differences in the computed environmental impacts don't arise from different electricity mixes, in this case.

Even though the technologies depicted in the found datasets slightly differ from the ones in use at the Swiss microtech company (steel composition, electricity mix, washing technology, etc.), the results of the comparison as well as the shares of each sub-process are considered as stable.

An uncertainty exists regarding the hardening step, which couldn't be modelled at all and whose share in the total environmental impacts still has to be computed. However, one can assume that its impact doesn't exceed the one from turning, as it can be seen as a simpler process, during which the hot metal pieces are quickly quenched by being dived into a liquid. This assumption should be validated with further investigations.

5.3 Recommendations

The conducted study provides answer elements to the overall research question, which is:

Are datasets of standard processes in existing databases valid to depict corresponding microtechnology processes?

The differences between the computed scenarios speak in favour of a negative answer to the research question. Based on the findings, the following three final comments are made:

- The existing datasets are not suited to assess the environmental impacts of the analyzed watch manufacturing of the two reference products
- Specific datasets for microtech processes should be developed
- Future analyses should assess the representativeness of the watch manufacturing sector for other microtech sectors, parallel to the development of microtech-specific LCI

6 Appendix

6.1 LCIA data

6.1.1 Overall

Table 2: LCIA results (overall comparison) in kg CO_2-eq. per kg of final product

GWP100 [kg CO2-eq.]	Wheel (Standard)	Wheel (Standard-modified)	Wheel (Microtech)	Axis (Standard)	Axis (Standard-modified)	Axis (Microtech)
Turning	1.10	40.39	430.29	1.10	152.17	1’365.37
Washing 1	0.02	0.02	4.19	0.05	0.05	13.16
Washing 2	0.02	0.02	4.19	0.05	0.05	13.16
Tempering	0.13	0.13	178.68	0.13	0.13	562.11
Polishing	0.00	0.00	8.28	0.00	0.00	26.05
Washing 3	0.02	0.02	15.57	0.05	0.05	48.97
Sum	1.30	40.59	641.19	1.32	152.39	2’028.82

Table 3: LCIA results (overall comparison) in UBP per kg of final product

UBP [Pt.]	Wheel (Standard)	Wheel (Standard-modified)	Wheel (Microtech)	Axis (Standard)	Axis (Standard-modified)	Axis (Microtech)
Turning	2’015	78’883	589’131	2’015	295’031	1’881’370
Washing 1	153	153	7’393	301	301	23’246
Washing 2	153	153	7’393	301	301	23’246
Tempering	78	78	277’124	78	78	871’787
Polishing	0	0	39’490	0	0	124’228
Washing 3	153	153	75’919	301	301	238’827
Sum	2’551	79’418	996’450	2’695	295’711	3’162’705

6.1.2 Sub-processes

Turning

Table 4: LCIA results (turning) in kg CO_2-eq. per kg of final product

GWP100 [kg CO2-eq.]	Wheel (Standard)	Wheel (Standard-modified)	Wheel (Micro-tech)	Axis (Standard)	Axis (Standard-modified)	Axis (Microtech)
Steel	0.45	22.39	22.39	0.45	82.20	82.20
Electricity	0.31	14.20	359.10	0.31	55.74	1129.68
Auxiliary	0.27	0.24	0.00	0.27	0.26	0.00
Oil	0.00	0.05	32.57	0.00	0.19	102.45
Others	0.08	3.51	16.23	0.08	13.78	51.04
Total	1.10	40.39	430.29	1.10	152.17	1'365.37

Table 5: LCIA results (turning) in UBP per kg of final product

UBP [Pt.]	Wheel (Stan-dard)	Wheel (Standard-modified)	Wheel (Micro-tech)	Axis (Stan-dard)	Axis (Standard-modified)	Axis (Micro-tech)
Steel	1'067	53'421	53'421	1'067	196'117	196'117
Electricity	375	17'114	432'750	375	67'167	1'361'360
Auxiliary	398	358	0	398	392	0
Oil	2	90	59'140	2	352	186'046
Others	173	7'899	43'819	173	31'003	137'847
Total	2'015	78'883	589'131	2'015	295'031	1'881'370

Washing

Table 6: LCIA results (washing) in kg CO_2-eq per kg of final product

GWP100 [kg CO2-eq.]	Wheel (Standard)	Wheel (Microtech)	Axis (Standard)	Axis (Microtech)
Solvent	0.00	0.66	0.00	2.08
Electricity	0.00	2.94	0.00	9.24
Waste mineral oil	0.00	0.59	0.00	1.84
Wastewater	0.01	0.00	0.01	0.00
Others	0.01	0.00	0.01	0.00
Total	0.02	4.19	0.02	13.16

Table 7: LCIA results (washing) in UBP per kg of final product

UBP [Pt.]	Wheel (Standard)	Wheel (Microtech)	Axis (Standard)	Axis (Microtech)
Solvent	0	1'438	0	4'511
Electricity	0	5'590	0	17'585
Waste mineral oil	0	366	0	1'151
Wastewater	133	0	133	0
Others	21	0	21	0
Total	155	7'393	155	23'246

Tempering

Table 8: LCIA results (tempering) in kg CO_2-eq per kg of final product

GWP100 [kg CO2-eq.]	Wheel (Standard)	Wheel (Microtech)	Axis (Standard)	Axis (Microtech)
Forming gas	0.00	117.12	0.00	368.45
Energy	0.13	61.56	0.13	193.66
Total	0.13	178.68	0.13	562.11

Table 9: LCIA results (tempering) in UBP per kg of final product

UBP [Pt.]	Wheel (Standard)	Wheel (Microtech)	Axis (Standard)	Axis (Microtech)
Forming gas	0	202’938	0	638’411
Energy	78	74’186	78	233’376
Total	78	277’124	78	871’787