Ontology-based analysis of the semiconductor supply chain

Ana Rita Salgado[1]

Abstract— **In line with the Paris Agreement requirements, companies' behaviours need to be adapted to the new environmental rules. Semiconductors industries, as a contributor to global warming due to their energy-demand manufacturing processes, can become an ally in the decarbonization of our society. Its primary contribution occurs when semiconductors are used in end applications, which often make these devices smarter, more energy-efficient, and even more affordable. To demonstrate the role of semiconductors in the reduction of Carbon Dioxide (CO2) emissions the Battery Management System (BMS) is taken as case study. A digitalised model based on an ontology is proposed to be included in the Digital Reference (DR) system, which serves as a data format for intelligent and effective communication between the parties involved in the semiconductor industry and related supply chains, as well as in other industrial areas. The Semantic Web will be the digital structure to design the DR. This additional part in the DR gives the possibility to the semiconductor manufacturers and consumers to assess the contribution of integrated circuits (ICs) to CO2 reduction.**

I. INTRODUCTION

As a consequence of the worldwide economic progress of the previous two centuries, natural resources are being depleted and levels of environmental pollution increasing. Such changes have an impact not only on human beings but also on natural systems. Climate change is now perceptible, with greater frequency and amplitude of extreme events such as droughts, floods, the average rise in air temperature and the melting of the polar ice caps, leading to rising sea levels. Such events bring unprecedented risks for vulnerable human populations and lead to irreversible biodiversity loss [1].

To tackle climate change and its negative impacts, world leaders at the UN Climate Change Conference (COP21) in Paris reached a historic agreement. Implementation of the Paris Agreement requires economic and social transformation, based on the best available science. The Agreement includes commitments from all countries to reduce their emissions and work together to adapt to the impacts of climate change and calls on countries to strengthen their commitments over time.

In order to mitigate the global warming problem, two aspects are analyzed in this research. First of all, the increase in transparency of the supply chains. With a more detailed analysis of our chains, it is possible to identify possible efficiency problems and avoid disruptions. On the other hand, to count on semiconductors as pillars in the transition to more efficient and greener equipment. The example of the BMS will be analyzed as a catalyst for this transition, in this case in the automotive sector.

With the electrification of our society and transition into the new industrial revolution, the Industry 4.0, semiconductors will gradually become more prominent in our electronic devices. Chips are the backbone of IoT, making them smarter, more user-friendly and energy-efficient, allowing the human-being to have a more comfortable lifestyle. The fast pace of the world accelerates the digitalisation of processes and consecutive semiconductor growth.

Semiconductor manufacturing is heavily polluting and requires large amounts of energy. However, its long-term environmental impact is strongly rewarding. Chips allow the creation of complex devices, digital or computational, capable of transforming systems, making them more efficient, less energy consuming and less pollutant, with very significant cumulative impacts in the long term.

To demonstrate this virtue, this work studied the impact of the BMS in terms of reducing the carbon footprint, particularly in electric vehicles. The main function of BMS is the supervision and management of lithium-ion batteries (LIBs), providing a safer use and longer life span. Another reason that makes the BMS a good choice is the relevance that this device will have in the transition to cleaner sources of transportation. The domestic transportation sector is responsible for the second biggest emissions in the EU, accounting for a quarter of the emissions [2]. The European Parliament has voted for a complete ban on new petrol and diesel cars by 2035. Therefore, the automobile market, namely the sales of Battery Electric Vehicles (BEVs) will be impacted by such a regulation. As a result, the need for smart technologies like the BMS, which is a device required for the usage of LIBs, will also peak.

After the analysis of the design of this equipment, a diagram reflecting its architecture and carbonic savings was built. An environmental analysis to this equipment was done, including the ways in which it contributes to CO2 savings. This scheme will serve as the base for the creation of an ontology. Semantic Web technologies support the development of ontologies, which allow standard knowledge sharing and give meaning to the data. The ultimate end of this work is to include such ontology in the semiconductor industry digital twin, the DR. This supra-ontology includes supply chains that contain semiconductors and semiconductors part of supply chains. This will proportionate the advantage of having a holistic view of the supply chain, a higher efficiency and scrutiny, due to a higher analytical capacity.

---

[1] Ana Rita Salgado is a Master's student in the Centre of Management Studies, Instituto Superior Técnico, University of Lisbon, 1049-001 Lisbon, Portugal, `ana.rita.salgado@tecnico.ulisboa.pt`

II. ANALYSIS OF THE SYSTEM ARCHITECTURE

The BMS system architecture can be subdivided into functional blocks and their respective semiconductors. The scheme from Figure 1 was made having as reference Infineon´s BMS technical report [3], resulting in this simplified version. This gives us a precise understanding of each element that constitutes the BMS, being a support tool for building the ontology. In the Figure it is represented the battery components, the functional blocks and the semiconductors that belong to each of them.

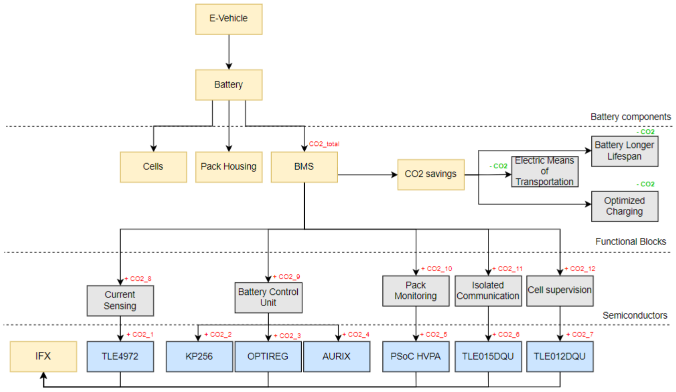


Fig. 1: Battery Management System - an architecture scheme

The BMS is a device that controls and regulates the charging and discharging of a battery, its key functionalities are among:

- Supervise the pack and cells parameters;
- Deduct the battery and cells states (SOC, SOH, SOP, SOS);
- Improve the battery performance by balancing the cells, inform to cool/heat the battery pack;
- Safeguard the battery from operating under hazardous and unsafe conditions.

This device allows a better management of the cells during their lifespan. Allowing a longer life cycle and the possibility of a second life. In addition, the digitalisation of such device into an ontology contributes to a more detailed life cycle description and consequent analysis and footprint reduction.

A. The role of the Battery Management System in CO2 savings

- Transition to Electric Means of Transportation: without the BMS, using LIBs would not be possible and this type of energy storage system is the most efficient and promising one. Therefore it is due to this semiconductors assembly that we are able to use it.
- Battery´s Longer Lifespan: with the usage of the BMS the battery cells are better managed which can reduce the necessity for replacement batteries and the associated manufacturing emissions.
- Optimized charging and usage: with this device, the cells are charged in an optimized way. Keeping pace with the optimal temperature, optimal voltage etc, assuring a longer lifespan. It ensures that the battery is working at the most efficient level, resulting in a reduction of energy consumption and lower emissions in its use.

B. Environmental analysis

Today we are witnessing a revolution in the means of transport. New transport vehicles will be powered by electric motors instead of traditional fossil fuel engines. These are, therefore, more ecological, and contribute to the reduction of greenhouse gas emissions. These are powered by electric batteries, mostly Lithium. However, without the BMS it would not be possible to use it effectively or with the required security. In this way, the contribution of the BMS in CO2 savings results from the combined sum of the (indirect) contribution of the batteries with the (direct) contribution of the improvement in efficiency achieved by the BMS. From the information available today, it is possible to determine the contribution of the BMS to CO2 savings, particularly due to its use in electric cars. From the known predictions about the growth of electric car use in the near future, it is also possible to estimate future CO2 savings. To answer these questions, a model will be proposed and the meaning of its parameters, constants and relationships will be explained. With this model, the total carbon emissions of electric cars circulating in the European Union in 2021 are calculated. From this value, the savings achieved by BMS are estimated. Figure 2 shows the proposed model (in the form of a flowchart) to calculate the CO2 savings by BMS.

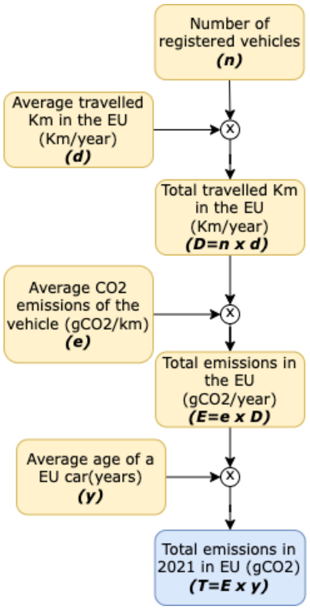


Fig. 2: Environmental analysis’ flowchart

The model´s parameters are:

- Nº of registered electric cars in the EU in 2021[4];
- Average distance travelled per year (Km/year)[5];
- Average CO2 emissions of a petrol/electrical car (gCO2/km)[6];
- Average age of the cars in the European Union (years)[7].

Two studies are presented to conclude regarding the BMS carbonic savings. The first study demonstrates the positive effects of having electric vehicles in circulation; the second study focuses on the carbonic savings inherent of the longer life expectancy of batteries.

- **Study 1: Carbon emissions from the circulating BEVs instead of petrol cars**

For this study was considered a vehicle, either an electric or petrol, with an age corresponding to the average in the EU of 11,5 years and with a consumption of the petrol and electric vehicles of respectively 127 gCO2/Km and 37.67 gCO2/km. This means that the average European electric vehicle emits 69% less than the equivalent petrol car [8]. In the year 2021, the number of BEVs, n, circulating in the EU was $1,729,000$ [4] and they made an average travel distance, d, about of 11300 km/year. The estimated number of kilometres travelled by cars, D, in the EU is, according to Eq. 1, 1.95×10^{10} km/year.

For petrol car: Taking into account the average carbon emissions of a petrol car, e, which is about 127 gCO2/Km, the total emissions produced by petrol cars in 2021 was, according to Eq. 2, 2.47×10^{12} gCO2/year (E). Since the average lifespan of petrol cars, y, in the EU is 11.5 years, the amount of CO2 produced, T, by these cars during their lifetime of use is, according to Eq. 3, 2.84×10^{13} tons of CO2.

For E-car: Now, in order to conclude regarding the CO2 saved with electric cars, the same analysis will be made considering the E-car emissions. Taking into account the average carbon emissions of an E-car, e, which is around 36.7 gCO2/Km, the total emissions from E-cars is, according to Eq. 1, 0.7×10^{12} gCO2/year. The amount of CO2 produced, T, by these cars during their lifetime of use is, according to Eq. 3, 0.8×10^{13} tons of CO2.

$$D = n \times d \tag{1}$$

$$E = e \times D \tag{2}$$

$$T = E \times y \tag{3}$$

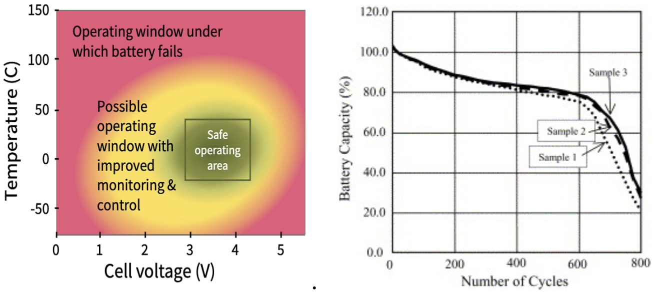
TABLE I: Environmental analysis data

Model Parameters	Petrol	E-Car
Number of registered vehicles in 2021, n	1729000	1729000
Average travelled Km in the EU (Km/year), d	11300	11300
Total Km travelled in the EU (Km/year), D	1.95×10^{10}	1.95×10^{10}
Average emitted CO2 by the vehicle (gCO2/Km), e	127	36.7
Total CO2 emitted in the EU per year (gCO2/year), E	2.47×10^{12}	0.7×10^{12}
Average age of an EU car (years), y	11.5	11.5
Total CO2 emitted through the vehicle's lifetime (gCO2), T	2.84×10^{13}	0.8×10^{13}

The saved CO2 due to the circulating electric cars instead of the petrol ones is done by subtracting the T values above calculated,i.e., $T_{petrol} - T_{E-Car}$. The savings reach up to 28% less of the emissions, with 2.04×10^{7} tons of CO2 saved.

- **Study 2**: **Battery Longer Lifespan**

When the Lithium-Ion cells are working, there is, as previously mentioned, a safe operating area in terms of voltage and temperature which guarantees efficiency and a safe usage. However, there is a chance that the BMS is able to broaden the operating area (i.e. the yellow region shown in Fig.3a), which maximizes the potential of the cells. This has some relevance in the SOC of the battery in its end-of-life, which is usually when it reaches 80% of its initial capacity. However, having this hypothesis into consideration, there is the possibility to use the battery until its capacity reaches 60% of its initial one [9]. As it can be seen in Fig.3b, the battery reaches 80% of its capacity after 600 cycles. However, if it works until 60% of its capacity, which means another additional 125 cycles, meaning an extra 20% of working cycles. Considering that a battery has a carbon footprint of 77 gCO2e/Kwh [8] in its manufacturing, and considering that a medium car needs a 60Kwh battery [8], it means that its footprint is 4620 gCO2e. Similar to the first part of this analysis, two scenarios will be described.



(a) Operating window [3]

(b) Capacity *vs* N. of cycles [10].

Fig. 3: (a) Operating window of a Li-Ion cell ;(b) Battery capacity characteristics.

Considering the manufacturing emissions of a battery for a medium car of 4620 kg CO2e and an average life expectancy of 15 years [11]:

- **Scenario 1**: Normal usage of the battery until it reaches 80% of its initial capacity, corresponding to 600 cycles. If the battery´s carbon footprint, 4620 kg CO2e, is divided by its number of cycles, 600 cycles, the footprint of the battery per cycle can be deducted, $7.7kg$ CO2e/cycle. When dividing the battery´s carbon footprint, 4620 kg CO2e, by its average life expectancy, 15 years, it is calculated the battery emissions per year, 308 kg CO2e/year.
- **Scenario 2**: Usage of the battery´s SOC until 60%, i.e. 20% extra Deep of Discharging, which allows the battery to have extra 125 cycles, having in total 725 cycles. As the battery can outlive an extra 125 cycles, this means 20% of additional lifespan, corresponding to 18 years instead of 15. Following the same reasoning

described above, dividing the battery´s carbon footprint, 4620 kg CO2e, by the number of cycles, 725 cycles, the battery is responsible for $6.4kg$ CO2e/cycle, emitting 9% less compared to the first scenario. Yearly, dividing the battery´s carbon footprint, 4620 kg CO2e, by the average life expectancy, 18 years, the battery emits around 6% less emissions per year than in the first scenario, corresponding to 271.8 kgCO2e/year.

After these studies, it can be concluded that the impact of this assembly of semiconductors, the BMS, is extremely positive, not only in the means of CO2 savings, but also as an ally in the shift towards more environmental means of transportation. In the first study, the carbonic savings proportioned by the registered electric cars in 2021 was of 2.04×10^7 tons of CO2 through the vehicle lifetime. In the second study, when optimizing the battery´s performance, extending its lifespan, it can be concluded that yearly, each battery emits less 6%.

III. BUILDING THE ONTOLOGY

Additionally, aligned with the Industry 4.0 goals, a digital twin of this device is developed. The Semantic Web Technologies allow the creation of ontologies, in this way, enabling a detailed analysis of the BMS's constitution. All its constituent parts will be defined with a standardized vocabulary, understood by both humans and machines. Such detailed characterization will contribute to standardized information and facilitate the process of analysis of its supply chain. For instance, by carefully examining the battery's life-cycle data, we may contribute to the study of how we might make the battery supply chain cleaner. This section will go into more detail about this procedure.

The design of this ontology is carried out in two parts. First, a global structure is defined. Next, it is translated by an ontology software into an appropriate code. For this task the Protégé software was used [12]. The steps followed to build the ontology are be highlighted here and then developed in their own sections [12][13] :

- Definition of the domain and scope;
- Determining the competency questions;
- Checking for previous existing ontologies;
- Listing important terms for the ontology;
- Defining the class hierarchy;
- Creating individuals;
- Defining the object properties;
- Transfer of the ontology into the Protégé.

A. Defining the domain and scope

The scope and the domain are important parts of an ontology. Both are defined by answering the following questions :

1) **What is the ontology sphere of coverage?** The main topic, is the representation of a BMS in a LIB. Its system architecture and main functions will be as well covered.
2) **What is the purpose of the ontology?**
This ontology has multiple objectives, among them is the creation of a digital twin of a semiconductor end-application, the BMS. Later on, it will be included into the DR, contributing to a higher holistic perception of the product. The CO2 savings possibilities of this end-application will be as well included in the ontology.
3) **For what should the ontology provide answers to?**
It must answer the questions: In which ways can the BMS contribute to CO2 savings? Which components are part of the BMS? Which semiconductors make part of the BMS?
4) **Who will use and maintain the ontology?**
This ontology will be integrated within the DR, which is a digital system that contains all the existing relationships in the semiconductor industry. Therefore, it will be used and updated by the multiple players in this industry.

B. Determining the competency questions

Answering a set of additional questions can help design a clearer, more concise and readable ontology. Such interrogations, give the possibility to test whether the ontology is sufficiently comprehensive and contains the necessary relations that answer the initial questions. These are:

1) What are the functional blocks of a BMS?
2) Which semiconductors are included in the BMS?
3) How can the BMS contribute to CO2 savings?

Analyzing these questions, it is predictable that the ontology will include information about the battery´s architecture, location and potential contribution for CO2 savings.

C. Check for previous ontologies

Before starting the process of building new ontologies, it is common to check the existence of those already in use. While doing this, the previous ontologies can be subjected to convenient updates in order to expand the knowledge about the processes or improve their structure, usually done in an iterative way. In this line of work, some libraries that include reusable ontologies present on the Web and in the literature were studied and here used, such as the ontology libraries Ontolingua[1] and the DAML[2]. In these libraries, searches were performed about BMS ontologies, using keywords such as "Battery Management System", "Battery" and "BMS". Given the insufficiency of results, the creation of an ontology for BMS is justified.

---

[1] http://www.ksl.stanford.edu/software/ontolingua/

[2] http://www.daml.org/ontologies/

D. *Ontology terms*

The next step in the ontology design will be to create a list of terms and words for the BMS ontology. Each domain ontology typically models domain-specific definitions of terms. Table II contains a list of terms, which are associated with specific categories of the current problem. They were collected from Infineon's BMS technical reports and data sheets [3].

TABLE II: List of important terms and its respective category

Category	Terms
Vehicle	E-Car Lithium-Ion Battery
Battery Components	Cells Battery Management System Pack
CO2 Savings	Battery Longer Lifespan Optimized Charging Electric Means of Transportation
Functional Block	Current Sensing Battery Control Unit Pack Monitoring Isolated Communication Cell Supervision
Semiconductor	TLE4972 KP256 OPTIREG AURIX PSoC HVPA TLE015DQU TLE012DQU
Semiconductor Company	Infineon

E. *Class hierarchy*

The class hierarchy of the BMS ontology is designed mainly to support computerized inference, if possible, in a readable and intuitive manner to a human end-user. The classes (and respective subclasses), individuals and properties will be defined in order to create a taxonomy. There are three ways in which the ontology can be organized, the *top-down*, *bottom-up* and *combination* [14]. The *top-down* approach begins by defining the domain's most general ideas, followed by the concepts' specialization.This structure is the most appropriate for the design of the BMS ontology. It first presents the general framework about the E-car, then about the battery components, followed by their functional blocks, to finally get to the semiconductor devices, becoming the information more specific and detailed at each next level. Table II presents an ordered list of terms by relevance factor for each category. The independent terms are selected. Thus, classes do not have terms that describe objects, but terms that have an independent existence [13]. Every object in a subclass is a "kind of" the superclass. From the list created, the classes were first selected, as suggested by [13]. The picked terms for classes were `Vehicle, Lithium Ion Battery, Battery Component, CO2 Savings, Functional Block, Semiconductor, Infineon`. After that, all the "kind of" the previously determined classes were selected as subclasses: `Optimized Charging, Electric Means of Transportation and Battery Longer Life Span` as a kind of CO2 Savings; the `E-Car` as a type of Vehicle and, finally, the different Functional Blocks like `Battery Control Unit, Cell Supervision, Current Sensing, Isolated Communication and Pack Monitoring`.

F. *Creating individuals*

Individuals (instances) are the basic components of an ontology that may include concrete objects, numbers and words. From Table II, the words `AURIX, KP256, OPTIREG, PSoC HVPA, TLE012DQU, TLE015DQU, TLE4972` belonging to the Semiconductors category, are "one of a kind" object, therefore, individuals groups.

G. *Defining the object properties*

Object properties define relationships between objects, having an associated range and domain for each one. Table III presents object properties, their range and their domain, where their elements obey a selected naming convention.

TABLE III: Ontology object properties, its range and domain

Object Property	Domain	Range
contributes_for_CO2_savings	Battery_Management_System	CO2_Savings
has_semiconductor	Pack_Monitoring Cell_Supervision Isolated_Communication Battery_Control_Unit Current_Sensing	Semiconductor
has_battery	E_Car	Lithium_Ion_Battery
has_component	Lithium_Ion_Battery	Battery_Component
has_functional_block	Battery_Management_System	Functional_Block
is_battery_component	Battery_Management_System Cells Pack	Battery_Component
is_functional_block	Pack_Monitoring Cell_Supervision Isolated_Communication Battery_Control_Unit Current_Sensing	Functional_Block
is_vehicle	E_Car	Vehicle
is_produced_by_Infineon	Semiconductor	Infineon
enables_CO2_savings	Electric_Means_Transportation Battery_Longer_Lifespan Optimized_Charging	CO2_Savings

IV. BMS - THE CASE STUDY

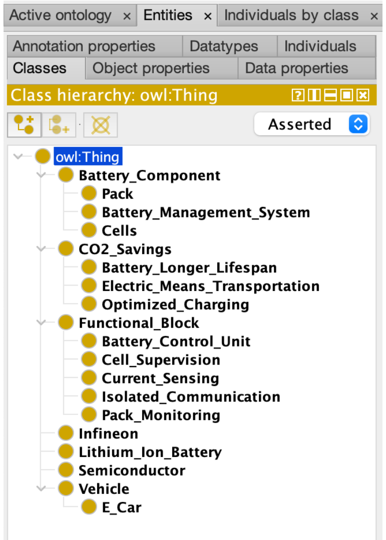
Protégé[3] was used to transpose the designed ontology structure to ontology code. It is the most popular and widely used ontology editor software in the world. The creation of the BMS ontology in Protegé followed a series of steps. First, the classes and subclasses were included in the project, as it can be seen in Figure 4. The subclasses can be seen under the classes `Battery_Component, CO2_Savings, Functional_Blocks, Vehicle`.

Secondly, the terms from the list, mentioned before, which are unique objects, referred by individuals or instances, were added next to the ontology.

Thirdly, the object properties are specified, which are terms that define relationships between objects. They have an associated range and domain components. Table III contains a list of different properties of objects, as well as the respective domain and subject where they were created. In the researched literature, there is no consensus about the terminology and the naming conventions to be used, particularly for BMS. For this reason, Infineon´s ontology naming convention [15] was here used for all the classes, subclasses, individuals and respective object properties. Elements of the table are written within Infineon´s convention. The classes and subclasses should be capitalized and separated by an underscore. Object properties, on the other hand, are written in lowercase letters and include verbs.

---

[3] https://protege.stanford.edu/



- owl:Thing
  - Battery_Component
    - Pack
    - Battery_Management_System
    - Cells
  - CO2_Savings
    - Battery_Longer_Lifespan
    - Electric_Means_Transportation
    - Optimized_Charging
  - Functional_Block
    - Battery_Control_Unit
    - Cell_Supervision
    - Current_Sensing
    - Isolated_Communication
    - Pack_Monitoring
  - Infineon
  - Lithium_Ion_Battery
  - Semiconductor
  - Vehicle
    - E_Car

Fig. 4: Classes and subclasses in the Protégé environment

A. *Ontology Validation*

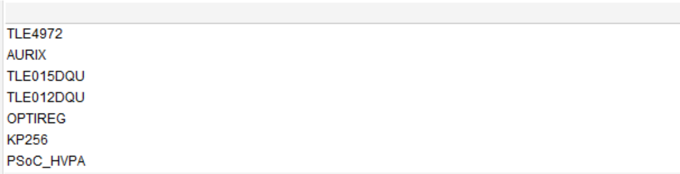
After the previously described steps, the ontology needs to be validated in order to check its coherence. One way to validate the ontology is to use the competency questions, formulated at the beginning of the ontology design, and turn them into queries. If the answers are as expected, it means the ontology is, with great probability, correctly connected and well formulated. In this work, these queries were written with the support of GraphDB software[4].

Queries development: The questions used for the validation process are similar to the competency questions above presented. Three queries were formulated, all from the type `SELECT`. The results of these queries have a shape of a table which shows all the elements that satisfy the conditions required. Due to space limitations, only one query is shown, Figure 5. The result of this query is presented in Figure 6, which is a complete list of the semiconductors that are part of a BMS. All the queries were successfully validated. The results of the additional queries included information on the BMS's various functional blocks and the corresponding CO2 savings provided by the BMS.

Which semiconductors are included in the BMS?

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX : <http://www.semanticweb.org/salgadoan/ontologies/2022/8/untitled-
    ontology-17#>
SELECT ?Semiconductors
WHERE {?Semiconductors rdf:type :Semiconductor.}
```

Fig. 5: Query for the second competency question



TLE4972
AURIX
TLE015DQU
TLE012DQU
OPTIREG
KP256
PSoC_HVPA

Fig. 6: The semiconductors of a BMS - answer to the query

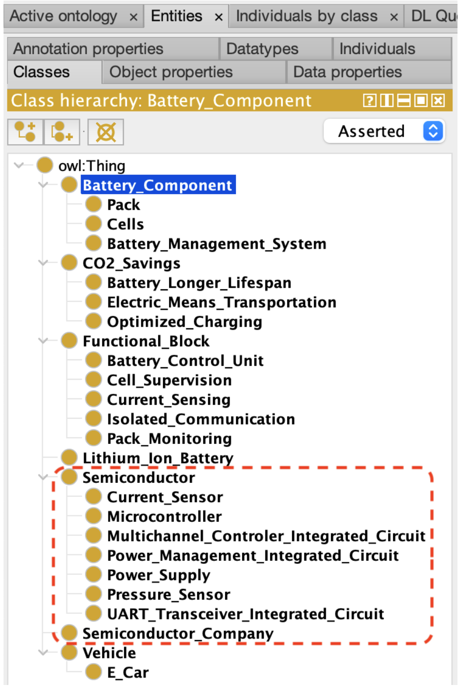
V. DIGITAL REFERENCE WITH BMS ONTOLOGY

The DR is a digital representation of semiconductor supply chains and supply chains containing semiconductors, used by most manufacturers and their retailers. It is therefore a digital platform for general use, involving multiple agents and including a huge variety of semiconductor devices, which are used in a wide variety of products and solutions. For this reason, it must have high levels of compatibility and usability. However, our proposed BMS ontology was formulated taking into account the specifics of Infineon's products. Consequently, it is not fully compatible with DR. But, with the following adjustments, it was possible to insert it. For instance, the individuals of the previous ontology, are now subclasses of the class `Semiconductor`. Also, each semiconductor is represented by its type of semiconductor, like presented in table IV. These new subclasses are in the dashes box of Figure 7.

In addition, the class `Infineon` was substituted by the class `Semiconductor_industry`, so that it fits all companies that manufacture a BMS. The digital twin is organized in topic clusters, represents all phases of the supply chain, and offers a knowledge base that is accessible to both computers and people [16]. It is an ontology in expansion, which integrates multiple ontologies.

TABLE IV: Changes in the old ontology

Infineon´s ontology	Digital Reference ontology
TLE4972	Current_Sensor
AURIX	Microcontroller
OPTIREG	Power_Supply
TLE012DQU	Multichannel_Controller_Integrated_Circuit
PSoC HVPA	Power_Management_Integrated_Circuit
KP256	Pressure_Sensor
TLE015DQU	UART_Transceiver_Integrated_Circuit
Infineon	Semiconductor_Company



- owl:Thing
  - Battery_Component
    - Pack
    - Cells
    - Battery_Management_System
  - CO2_Savings
    - Battery_Longer_Lifespan
    - Electric_Means_Transportation
    - Optimized_Charging
  - Functional_Block
    - Battery_Control_Unit
    - Cell_Supervision
    - Current_Sensing
    - Isolated_Communication
    - Pack_Monitoring
  - Lithium_Ion_Battery
  - Semiconductor
    - Current_Sensor
    - Microcontroller
    - Multichannel_Controler_Integrated_Circuit
    - Power_Management_Integrated_Circuit
    - Power_Supply
    - Pressure_Sensor
    - UART_Transceiver_Integrated_Circuit
  - Semiconductor_Company
  - Vehicle
    - E_Car

Fig. 7: Digital Reference ontology - classes and subclasses in the Protégé

---

[4] https://graphdb.ontotext.com/documentation/10.0/index.html

VI. CONCLUSIONS

Semiconductors are essential to the transition to greener devices and the decarbonization of society. They play a primary role in digitalisation of the information, namely in the semiconductor supply chain digitalisation.

In this paper is proposed a new method, based on a web ontology, that allows the estimation of the contribution and the benefits of the semiconductors in the context of a greener society. The BMS was used as a case study due to its importance for batteries management and E-cars. This study shows that semiconductors are indispensable to BMS and essential towards the carbon footprint reduction. They, simultaneously, improve the energetic efficiency, the safety and the batteries cells' lifespan, therefore contributing to the reduction of the CO2 emitted by vehicles and electric equipment. The estimation of CO2 savings was computed, showing values that prove the importance of the BMS and its semiconductors.

Additionally, a BMS ontology was proposed to be included in DR. Its design was explained step by step. The DR is a useful tool to measure and collect relevant data of semiconductors devices, from manufacturers, through markets and until end-consumers. This will have an impact on possible disruptions in the supply chain, by reducing their effects through quicker response to such situations. In such a global and complex supply chain like the semiconductors one, this digitalisation is crucial to avoid these type of phenomenons, for instance, the chip shortage during the COVID-19 pandemic. The huge impact of this event accelerated the switch to more connected supply chains and more transparency, with higher information sharing and more diversified suppliers. Therefore, a more optimized network with a better risk management. In terms of sustainability, having an holistic vision and control of the network allows a higher awareness regarding the manufacturing conditions and origin of the products, instigating as well social responsibility. The contribution made with the BMS ontology to the DR was of high relevance and a contribution for the transition into the Industry 4.0.

REFERENCES

[1] IPCC, *IPCC 6th Report - Chapter 1*, 2021.

[2] E. Parliament, "Eu ban on sale of new petrol and diesel cars from 2035 explained," 2023.

[3] M. Ismail, P. Leteinturier, F. Weidner, M. Ekler, K. Scheibert, N. Sivaguru, J. Heinzelmann, and K. Sukumar, "Understanding and overcoming the challenges of building high voltage automotive battery management systems."

[4] European Environment Agency, "New registrations of electric vehicles in europe," 2022, [Online; accessed 13-February-2022]. [Online]. Available: https://www.eea.europa.eu/ims/new-registrations-of-electric-vehicles

[5] Enerdata, "Change in distance travelled by car," 2019, [Online; accessed 13-February-2022]. [Online]. Available: https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html

[6] European Environment Agency, "Average co2 emissions from new cars and new vans increased again in 2019," 2020, [Online; accessed 13-February-2022]. [Online]. Available: https://www.eea.europa.eu/highlights/average-co2-emissions-from-new-cars-vans-2019

[7] E. A. M. Association, "Vehicles in use in europe," 2021.

[8] Transport&Environment, "T&e analysis of electric car lifecycle co2 emissions," 2022.

[9] M. Ismail and A. Salgado, "Interview made to an expert via online," 2022.

[10] "Influence of cycle capacity deterioration and storage capacity deterioration on li-ion batteries used in mobile phones," *Journal of Power Sources*, vol. 142, no. 1, pp. 298–305, 2005.

[11] Nationalgrid, "What happens to old electric car batteries?" 2022, [Online; accessed 01-January-2023]. [Online]. Available: https://www.nationalgrid.com/stories/journey-to-net-zero-stories/what-happens-old-electric-car-batteries

[12] M. Horridge, H. Knublauch, A. Rector, R. Stevens, C. Wroe, S. Jupp, G. Moulton, N. Drummond, and S. Brandt, "A practical guide to building owl ontologies using protégé 4 and co-ode tools edition 1.3," 2011.

[13] N. F. Noy and D. L. Mcguinness, "Ontology development 101: A guide to creating your first ontology."

[14] M. Uschold and M. Grüninger, "Ontologies: Principles, methods and applications," *The Knowledge Engineering Review*, vol. 11, 01 1996.

[15] W. Kusnierczyk, S. E. Lewis, J. L. Scibite, B. Smith, D. Schober, S. E. Lewis, J. Lomax, C. Mungall, P. Rocca-Serra, and S.-A. Sansone, "Towards naming conventions for use in controlled vocabulary and ontologyengineering," p. 5.

[16] H. Ehm, N. Ramzy, P. Moder, C. Summerer, S. Fetz, and C. Neau, "Ecsel digital reference – a semantic web for semiconductor manufacturing and supply chains containing semiconductors."