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Publishable Executive Summary

AIMS5.0 is a pan-European initiative to boost industrial competitiveness through inter-disciplinary innovations, establishing sustainable Electronic Components and Systems (ECS) value chains and therefore contributing to European Digital Sovereignty by addressing urgent issues like Security of Supply, Monitoring and Crisis Response, and Chip Shortage.

This deliverable is part of Work Package 4 (WP4) to build an Open Access Platform (OAP), which will enable the exchange of knowledge graphs within the supply chain of the semiconductor industry domain. The vision is that users can contribute to the platform by adding information and collaboratively refining it while ensuring the information is valid and accurate. Additionally, the OAP should support ontology learning, validation, and manual post-processing. In charge of WP4 are Infineon Technologies AG, DAC.digital, Fern Universität Hagen, and NXP Semiconductors.

The focus for the first milestone lies in determining the company's internal supply chain greenhouse gas (GHG) emissions. With the goal to reach net zero by 2030, it is imperative to find the individual emission contributors to create a sustainability strategy. To address this, this document contains ontologies that enable to determine the CO_2 emissions that can be saved through the improvement of Infineon Technologies AG products (semiconductor products) in different use cases such as conventionally powered and battery electric vehicles, solar PV technology and wind turbines. Additionally, internally planned/external transportation emissions are introduced to be added to the OAPs digital reference (DR). Furthermore, ontologies breaking down the relevant variables to analyze the CO_2 footprint of different manufacturing locations are presented.

Thus, the WP4 strives to establish a standardized and modular semantic description of industrial domains and supply chains using the Digital Reference ontology. Ontologies integrated in the DR provide the framework to determine the GHG emissions in a structured manner to investigate the goals of the AIMS 5.0 project.

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1. Introduction

1.1 Objective and scope of the document

AIMS5.0, a collaborative Innovation Action aims at strengthening European digital sovereignty in comprehensively sustainable production, by adopting, extending, and implementing AI-enabled hardware and software components and systems across the whole industrial value chain to further increase the overall efficiency. The project is a large and complex European innovation action, requiring adequate management and quality assurance structures. The key characteristics of the KDT JU project are:

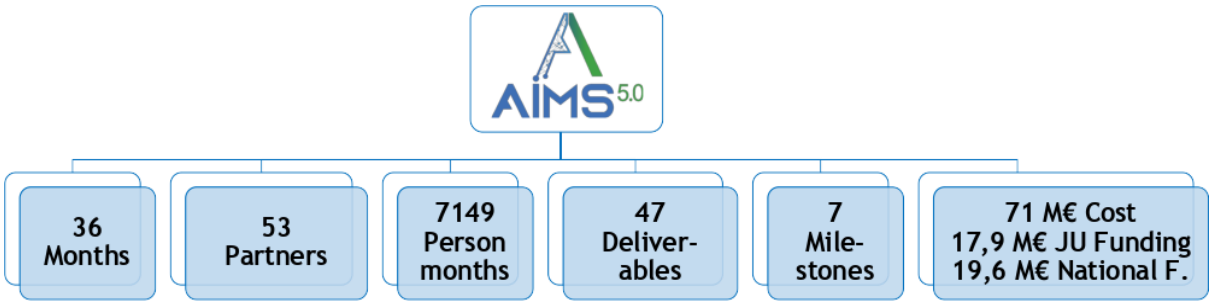

Figure 1: AIMS5.0 key characteristics

Vulnerability of existing supply chains in crisis shows the need for shorter supply chains and for keeping production in Europe. AI enabled fabs will be given more output and higher sustainability, which makes them more competitive on a global scale. New technologies from IoT and based on semantic web ontologies, ML and AI will help to enable the transformation from Industry4.0 to Industry5.0, to create human centric workplace conditions and to enable the transformation of European industry to climate-friendly production. Above all, sustainability and resilience will be improved.

The work package 4 (WP4) discussed in this deliverable strives to establish a consistent and modular semantic description of industrial domains and supply chains using the Digital Reference (DR) ontology. The OAP delivered with the WP4 will enable the exchange of knowledge graphs for the project collaboration. Figure 2 shows the current OAP architecture.

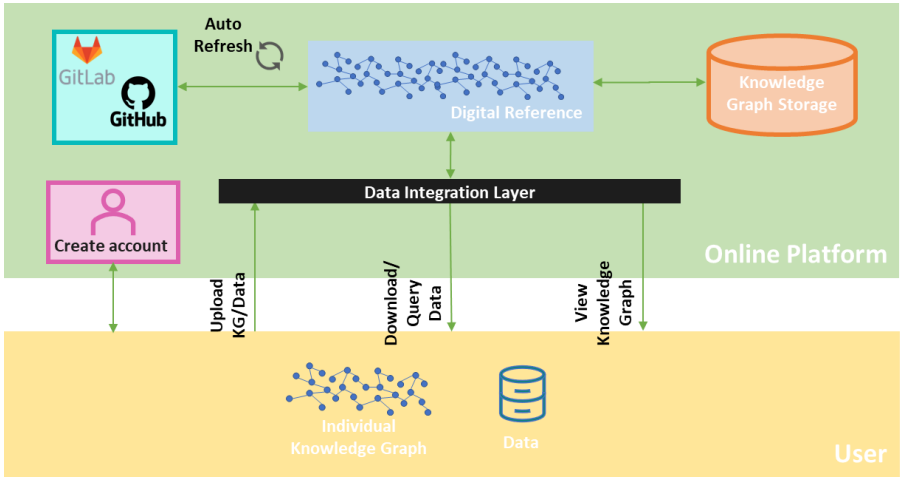

Figure 2: Functional overview of the OAP

The applications to be collaborated on the platform with the project partners are sustainability, planning and Quality Management (QM). The OAP is functionally divided into one platform to share structural knowledge in form of knowledge graphs and one platform to transfer data securely by applying the DR and individual knowledge graphs. The User Platform relates to the Online Platform. The main target of the User Platform is to provide different functions. These functions include for example: Upload/Download knowledge graphs, querying data or viewing the knowledge graphs. This OAP will bring advantages in scalability, updating and efficiency or straightforward collaborations. In the AIMS5.0 project the output from the OAP is used to achieve a more sustainable way of manufacturing. The specific focus in this document lies in the extension to sustainability for the internal semiconductor supply chain.

1.2 Structure of the deliverable report

In the beginning of the deliverable section 2 is providing a short introduction to Infineon Technologies AG (IFAG), moreover to the supply chain and production process as well as to the internal supply chain. To elaborate section 2 section 3 is focusing on the sustainability at IFAG. Therefore, the 3 scopes of Greenhouse Gas (GHG) emissions are defined and the carbon footprint through products from IFAG is described. In section 4 the document outlines the use case, while defining the so-called Digital Reference (DR) which represent the different entities in the semiconductor manufacturing process. Chapter 5 describes the use cases containing IFAG products with existing ontologies in the DR. The classes of the sustainability lobe are explained, with the ontologies of the mobility sector and the renewable energy technology sector. Subsequently, section 6 intends to provide examples for potential ontologies that can be merged to the digital reference to determine the internal supply chain CO_2 emissions. The objective is to identify and categorize various contributors to emissions, encompassing energy consumption patterns, transportation, and manufacturing processes. Finally, chapter 7 draws conclusions of the collected results from this deliverable and gives an outlook.

2. Introduction to IFAG supply chain

2.1 General information IFAG

Infineon Technologies AG (IFAG) is a worldwide leading semiconductor company. The company currently occupies 56.200 employees. In total there are 20 manufacturing locations (13 Back End (BE), 7 Front End (FE) and one location fulfilling both) and 56 Research & Development (R&D) locations [1]. IFAG is operating in the semiconductor industry with customers located worldwide. The company is profiting from one of the fastest growing industries. The market size has evolved over the last two decades from 204 billion USD in 2000 to 298 billion USD in 2010 and up to 573 billion USD in 2022. IFAG generated a revenue of €14.2 billion in the 2022 fiscal year, a 29 percent increase on the previous year's figure of €11,060 million [20]. The company is divided into four segments: Automotive, Power & Sensor Systems, Connected Secure Systems and Green Industrial Power. Within these segments IFAG is offering a variety of products. Single products such as sensors, transistors or diodes, or entire applications. The application products are designed, e.g., for smart home, automotive, or communication sectors [3]. IFAG aims to be carbon neutral by the year 2030. Therefore, it is reducing its own direct emissions of greenhouse gases (GHG) but also indirect emissions from electricity and heat production. Moreover, the products and innovative solutions IFAG is developing contribute to combat climate change and reach a sustainable future [2].

2.2 Supply chain and production process

The organization of IFAG's supply chain is based on the so-called Supply Chain Operations Reference (SCOR) model that was developed by the APICS Supply Chain Council to support companies in designing their supply chain related activities. The SCOR model describes a value chain consisting of five management processes: plan, source, make, deliver, and return. The beginning of the semiconductor supply chain is marked by the delivery of raw material from the suppliers. The wafers consisting of pure silicon are stored in the wafer stock before entering the manufacturing process, which can be distinguished as FE and BE manufacturing. The production process of chips is comprehensive, therefore, IFAG has its own production system. The whole process is illustrated in Figure 3.

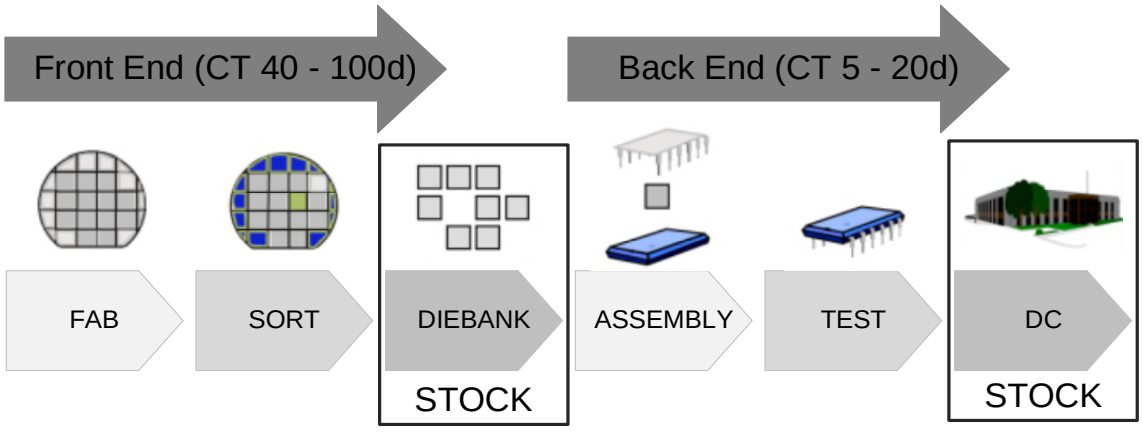

Figure 3: Production process of IFAG.[4]

The FE process comprises wafer fabrication and sorting. The subsequent BE process consists of assembly and testing. A typical FE cycle time is between 40 and 100 days, the cycle time in the BE lies between 5 and 20 days. In wafer fabrication, multiple layers of material with different

electrical characteristics are added on the wafer. Up to several thousand Integrated Circuits, also referred to as chips, can be realized on one single wafer, depending on its diameter. Thereafter, the fabricated wafer's electrical properties are tested for production related defects. The Die bank is the interface between FE and BE, with the manufactured wafer lots from the FE being stocked. One lot aggregate 25 to 50 wafers. After FE manufacturing, the wafer lots are shipped to the BE for assembly, testing and packaging. In the assembly, wafers are cut into individual pieces, called die's, in preparation to glue or solder them to a lead-frame. This is followed by the wire bonding process and a visual inspection of the semi-packaged products. The dies are then encapsulated by a mold compound and a deposited layer of material to protect them from the environment. In assembly, the chips are separated and shaped into individual pieces. Afterwards, final tests ensure that the packaged chips fulfil their functions according to their – often customer-specific – product specifications. Finally, the chips are shipped to the distribution center or directly to the customer. The long cycle times in the production process, the short product lifecycle, and steep product ramp-ups and ramp-downs are big challenges in the semiconductor industry. The semiconductor industry is positioned very early in the value chain. Additionally, the markets behave dynamically, making demand forecast difficult. Therefore, there is limited demand visibility and because of dynamic markets, the demand is difficult to forecast. This complexity is addressed by the so-called Digital Reference.

2.3 Internal supply chain

The internal supply chain refers to the complex network of processes and activities that occur within an organization's own facilities and operations. It encompasses the management of materials, information, and resources necessary to produce goods or deliver services efficiently. The primary goal of the internal supply chain is to ensure that products or services move seamlessly from initial production stages to final delivery, all while optimizing processes, reducing costs, and maintaining quality within the organization's boundaries.

Extending sustainability within the internal supply chain involves integrating environmentally and socially responsible practices into the internal processes and operations. This means going beyond the traditional focus on efficiency and cost reduction to consider the broader impact of the organization's activities. Sustainability efforts within the internal supply chain may include reducing energy consumption, minimizing waste generation, implementing responsible sourcing and production methods, and promoting ethical labor practices. In essence, it entails aligning the organization's operations with principles that prioritize environmental stewardship, social responsibility, and long-term economic viability, contributing to a more sustainable and resilient business model.

3. Sustainability at IFAG

Over the next decade, decarbonization and digitalization are set to bring about profound changes on a global scale, marking the beginning of a substantial economic and social transformation. The world's energy-related carbon dioxide emissions from energy combustion and industrial processes rebounded to 36.6 Gt in 2021, the largest ever annual rise (6%) in emissions, as showed in Figure 4. Addressing crucial matters such as transitioning energy sources, optimizing resource usage, advancing sustainable and intelligent transportation, and enabling seamless connectivity requires a determined approach grounded in technological progress. In this context, IFAG recognizes these pressing global challenges as an extraordinary opportunity for progress.

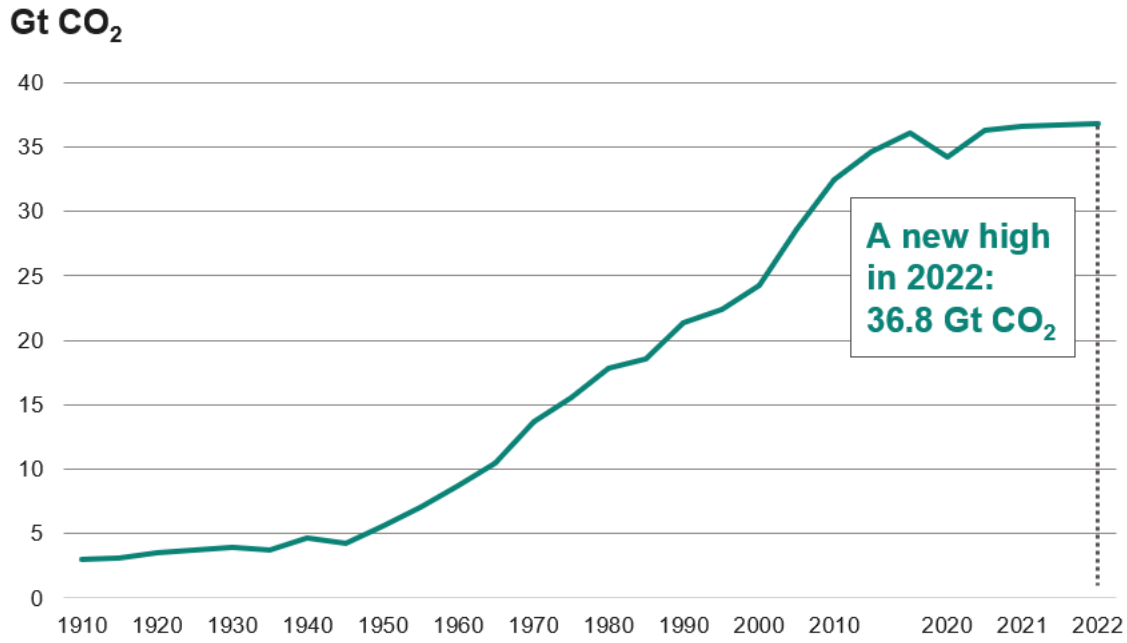

Figure 4: Carbon dioxide emissions from energy combustion and industrial processes

Semiconductors play a crucial role in the transition to a sustainable society and economy. Without them, renewable energy, the charging infrastructure for electromobility and secure communication between connected devices are all inconceivable. Its know-how and its innovative capacity make IFAG a key player in a green transition and the digital transformation. Its solutions enable a "net-zero" economy and connect the real world with the digital world. This represents the company's significant contribution to shaping a sustainable future.

Given the complex challenges, sustainable action balancing economic, environmental, and social has assumed unprecedented relevance. For IFAG, sustainability has consistently represented a commitment that extends beyond mere adherence to regulations. For years, IFAG has prioritized CO_2 avoidance and conservation of resources, especially in its manufacturing. On the road to carbon neutrality, we achieved significant milestones by using green electricity in Europe and North America and completing the abatement system in Kulim. As a result, the company uses resources in its production processes today in a much more efficient way than the global average in the semiconductor industry. Nevertheless, IFAG is actively engaged in progressive pursuits. Its commitment to curtailing its carbon footprint persist unwaveringly. The company is already making a valuable contribution to climate protection through its products and solutions and its own efficiency measures [19].

3.1 Sustainability overview at IFAG

IFAG's commitment to sustainability is manifest through its strategic initiatives aimed at mitigating climate impact. With a resolute vision in mind, IFAG has charted a course towards carbon neutrality by the conclusion of the fiscal year 2030 concerning its Scope 1 and Scope 2 emissions, as defined in 3.2 section. Taking its sustainability goals even further, IFAG has set a definitive target to curtail its own emissions by a remarkable 70 percent by the close of the fiscal year 2025, relative to the emissions recorded in the 2019 calendar year, as evidenced in Figure 5. These objectives not only reflect the company's proactive stance in advancing global CO_2 reduction but also aligns harmoniously with the aspirations delineated in the Paris Climate Agreement, which limit global warming to well below 2.0, preferably to 1.5 degrees Celsius compared to pre-industrial levels

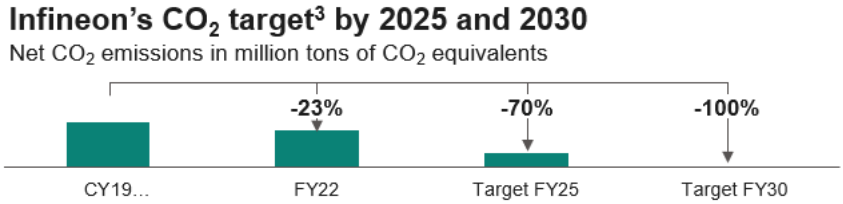

Figure 5: Infineon's CO2 target by 2025 and 2030

In line with this objective, IFAG directs its efforts toward mitigating direct emissions and enhancing energy efficiency. Furthermore, the company is augmenting its emission reduction endeavors by prioritizing the procurement of green electricity, further reinforcing its commitment through participation in the corporate initiative RE100. This global alliance unites major businesses committed to 100 percent renewable energy, collectively aiming to expedite the transition to a decarbonized economy. As part of its comprehensive strategy, IFAG also plans to offset unavoidable emissions through the acquisition of CO_2 certificates, amalgamating development assistance with carbon mitigation. This holistic approach solidifies Infineon's dedication to a sustainable future and its pivotal role in fostering positive change within the semiconductor industry and beyond [19].

3.2 Greenhouse gas emissions

At an early stage, IFAG started developing strategies to reduce energy consumption as well as the amount of material used to the minimum technically necessary, thereby limiting CO_2 emissions [19]. Understanding IFAG's sustainability requires exploring Scopes 1, 2, and 3 emissions definitions, as these concepts are essential for measuring the company's carbon footprint. Scopes 1, 2, and 3 are categorizations used to classify GHG emissions related to human and business activities, providing a framework for understanding and quantifying different emission sources.

3.2.1 Scope 1 emissions

Scope 1 emissions are direct emissions from a company’s owned or controlled sources. This includes on-site energy, such as natural gas and fuel, refrigerants, and emissions from combustion in owned or controlled boilers and furnaces, as well as emissions from fleet vehicles. These emissions also encompass process emissions that are released during industrial processes and on-site manufacturing [12].

The semiconductor industry is a significant contributor to Scope 1 emissions, using GHG in wafer-etching processes for structuring wafers and for cleaning production equipment. This includes perfluorinated compounds (PFC), namely perfluorinated and polyfluorinated carbon compounds, sulfur hexafluoride and (SF_6) and nitrogen trifluoride (NF_3). Despite all scientific research, there is no viable alternative to replace all PFCs used in the semiconductor industry. These greenhouse gases account for 80.7 percent of Scope 1 emissions [19]. Where possible and appropriate, IFAG counters this trend by continually:

- Optimizing its processes through more efficient production methods and through efficient exhaust air abatement schemes.
- Using alternative gases with higher utilization rates and lower GHG potential.
- Investing voluntarily in PFC exhaust air abatement to avoiding around three quarters of its potential direct Scope 1 emissions, which corresponds to avoiding around 738,054 tons of CO_2 per year.
- Setting itself the target of implementing measures that will generate total emission savings of 50,000 tons of CO_2 equivalents by the end of the 2024 fiscal year. It expect to achieve this mainly through PFC reduction measures.

Its Scope 1 emissions in the 2022 fiscal year totaled 312,076 tons of CO_2 equivalents. IFAG's targeted efforts to cut Scope 1 carbon emissions, in conclusion, highlight the company's proactive commitment to reducing direct environmental effect [19]. These initiatives demonstrate the company's commitment to ethical business conduct and set an inspiring example reaching carbon neutrality through innovative and technological initiatives.

3.2.2 **Scope 2 emissions**

Scope 2 emissions include indirect emissions from purchased or acquired energy, like electricity, steam, heat, or cooling, that is generated off-site and consumed by the reporting company [12]. Through a range of strategic initiatives and investments, the company is resolutely dedicated to reducing its indirect GHG emissions arising from purchased electricity consumption. These efforts reflect IFAG's overarching commitment to sustainable practices and its contribution to global efforts in combating climate change. Where possible and appropriate, IFAG counter this trend by continually:

- Utilizing green electricity across its operations in Europe and North America. This strategic shift towards renewable energy sources showcases IFAG's commitment to minimizing its carbon footprint and contributing to a greener future.
- Performing regular reviews at its sites to identify potential in its own electricity supply.

Its Scope 2 emissions in the 2022 fiscal year totaled 574,595 tons of CO_2 equivalents. IFAG's efforts to reduce Scope 2 carbon emissions demonstrate this commitment by tackling these issues indirectly. Despite its remarkable efforts, the potential for its own green electricity production on its sites is limited due to the topology of the buildings and other factors and is in the lower single-digit percentage range regarding its total electricity consumption [19].

3.2.3 **Scope 3 emissions**

Scope 3 includes all indirect emissions that occur in the value chain of a reporting company [12]. At IFAG, Scope 3 emissions encompass a wide range of activities, including emissions generated for the provision and disposal of raw materials and suppliers, utilities, operational materials, and other process media, goods transportation, travel, and energy supply activities, and manufacturing service providers. Scope 3 emissions in the fiscal year of 2022 totaled 2,143,685 tons of CO_2 equivalents [19].

3.2.4 Contribution through sustainable products

IFAG's climate strategy is based in two pillars. In addition to continuing to reduce its own emissions, the company actively contributes to climate protection through its innovative products and solutions. Given that IFAG's products are essential to furthering the energy and mobility revolutions, the company recognizes that it has a dual obligation to grow its business while also minimizing its environmental impact. The company believes that the new technologies that enable using fewer resources and save emissions are fundamental to achieve heightened sustainability and solving climate related challenges. Furthermore, IFAG conducts regular analyses of current trends as part of its definition of new products to identify sustainable business models.

Semiconductors from IFAG help generate electricity from renewable sources. Additionally, they provide greater efficiency throughout the whole energy value chain, including generation, transmission, storage, and particularly in the consumption of electricity, as shown in Figure 6. They serve as the cornerstone for the intelligent and effective use of energy, including in motor vehicles, industrial applications, and power sources for computers and consumer devices. IFAG's solutions enhance end-product efficiency, aiding environmental sustainability in industries like electromobility and renewable energy. Semiconductors optimize energy conversion, notably in electric vehicles, while also supporting wind and solar energy generation. Hence, IFAG is making a significant contribution to decarbonization in supply chain and in end applications [19].

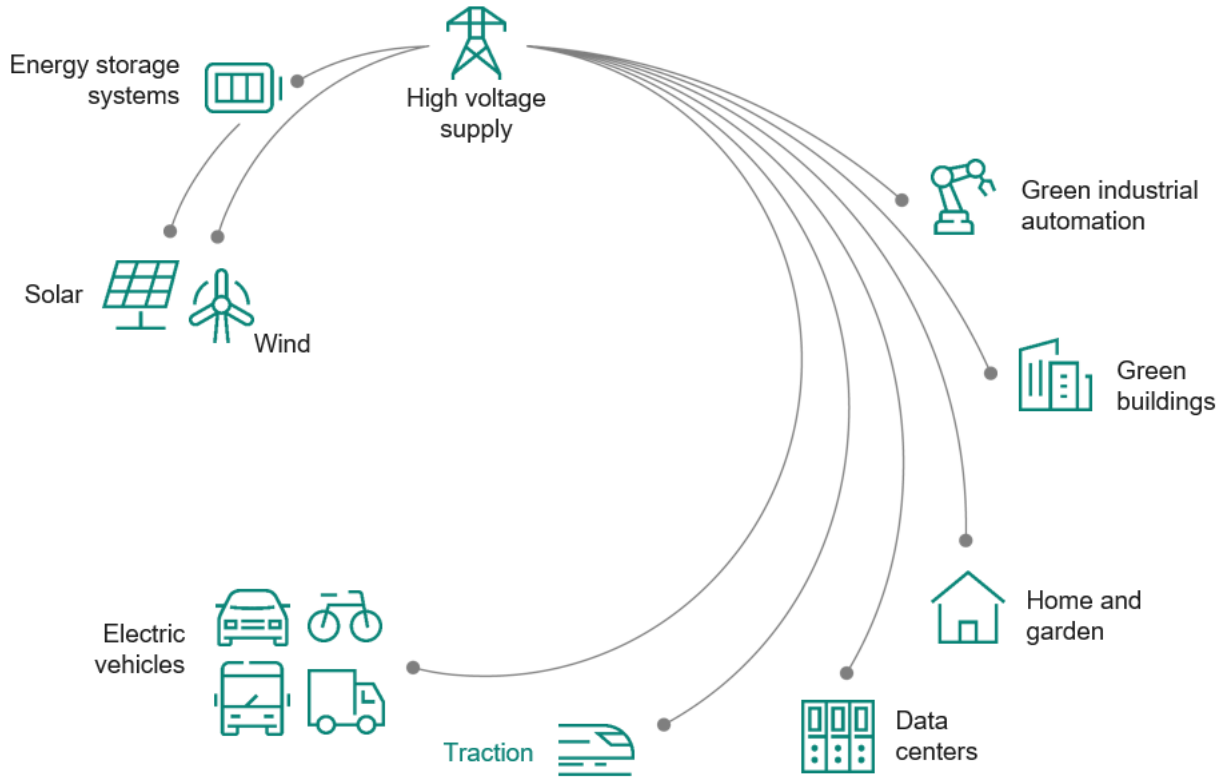

Figure 6: Optimization of energy efficiency along the energy conversion chain enabled by Infineon products

3.2.5 The IFAG carbon footprint

When calculating a carbon footprint, it's crucial to consider complex processes and a wide range of influencing factors. As a result, carbon footprint calculations often involve making certain

estimations. IFAG is committed to continually improving the accuracy of these estimates by optimizing its approach. In the calculation of IFAG's carbon footprint, the company considers the entire manufacturing process in accordance with the GHG Protocol. This includes not only raw materials and suppliers but also internal and external logistics, including final distribution.

IFAG's product line plays a pivotal role in reducing carbon emissions, with the potential to decrease carbon dioxide output by approximately 100 million tons of CO_2 equivalents throughout their operational lifetimes. This contribution becomes even more significant when you consider that Infineon emits 3 million tons of CO_2 in contrast. The adoption of these cutting-edge products and solutions by Infineon's clients results in an impressive ratio where the avoidance of CO_2 emissions is currently 33 times greater than the emissions generated during the production process. In a comprehensive assessment, the combined impact of Infineon's offerings, both in terms of carbon savings and its own emissions, resulted in a substantial net reduction of 97 million tons of CO_2 equivalents over the past fiscal year. This remarkable reduction underscores Infineon's unwavering commitment to sustainable practices and environmental accountability, solidifying its position as a responsible industry leader [19].

4. Digital Reference (DR)

The DR is a Semantic Web-based ontology that represents entities being relevant for semiconductor manufacturing and manufacturing employing semiconductors [5]. Semantic Web aims to convert the current web from an unstructured and semi structured document into a ”web of data” [6]. The Semantic Web works as an extension of the current web, which enables computers and people to work in better cooperation [7]. The Semantic Web describes the relationship between the classes using Resource Description Framework (RDF), Web Ontology Language (OWL), and Extensible Markup Language (XML), which enable to provide machine-readable descriptions and append meaning to the content of the web documents [8]. To conduct queries, SPARQL Protocol and RDF Query Language (SPARQL) is used. DR is a successful application of the Semantic Web, resulting from the Productive4.0 project [9]. Productive4.0 was a European research project in which 109 partners were involved to achieve improvement in digitizing European industries. IFAG integrated the Semantic Web technology into the project to enhance digitalization of the semiconductor supply chain. Figure 7 shows the present status of the DR. There are now 14 domains, so-called lobes in the DR, with the dots denoting the classes connected with each other based on their relationship. The resulting DR for semiconductors describes the production- and development processes, and their supply chain. It is continuously further developed, mainly in the SC^3 project, resulting in improvements and its expansion [10]. Furthermore, the DR will serve as the foundation for the funded project AIMS5.0, boosting digital manufacturing, agility, flexibility, and the integration of AI for manufacturing systems and supply chain performance.

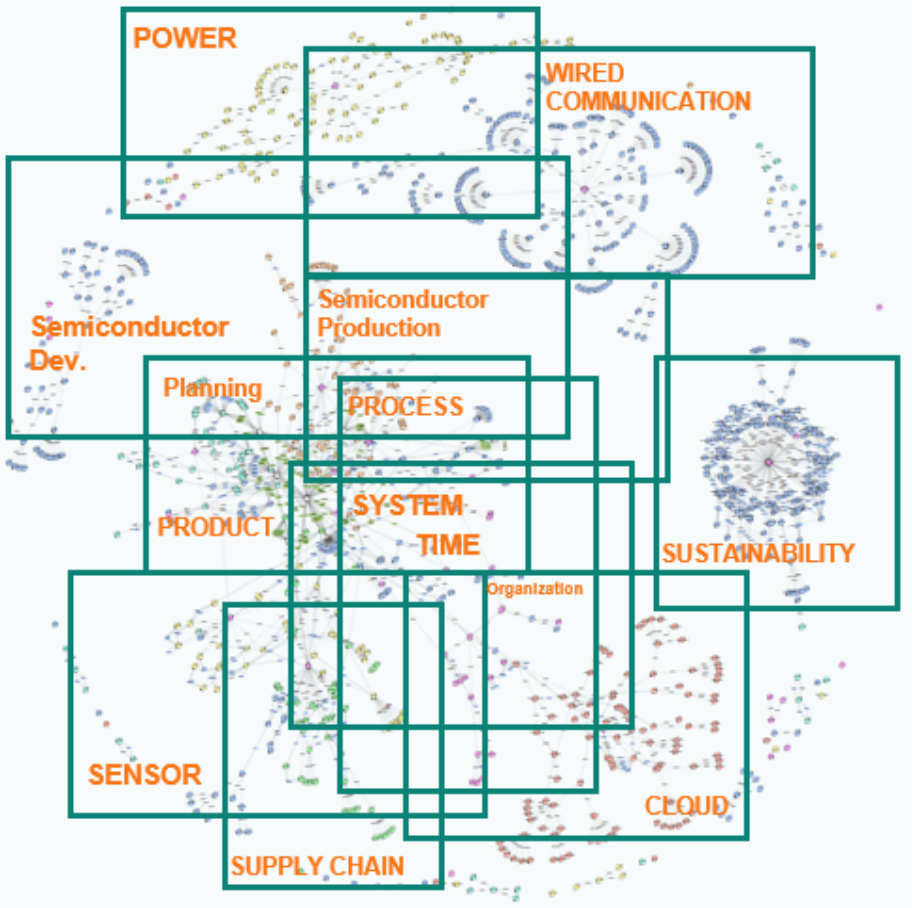

Figure 7: DR [11]

5. CO_2 savings through IFAG products

This chapter describes the use cases containing IFAG products with existing ontologies in the DR. The objective is to determine the product influence on reducing the CO_2 emissions in the application. IFAG products make conventional and battery electric vehicles (BEVs) more sustainable. Additionally, they increase the performance of renewable energy technology such as solar photovoltaic (PV) and wind turbines. In the following, these applications and correlating IFAG products are described.

5.1 IFAG product application in the mobility sector

Resource scarcity, climate change and growing energy demands accentuate the need for sustainable mobility choices worldwide. The answer lies in low- and zero-carbon mobility concepts that are fit for the future. A climate-friendly mobility ecosystem hinge, however, on energy efficiency across the entire power chain from generation through distribution right up to the point of use. Semiconductors are the key enablers behind a sustainable mobility vision. They play a vital role in building energy efficiency into all steps of the energy supply chain and build the basis for electrifying a broad range of different vehicles for a greener future. IFAG products in the transportation sector are used in both Internal Combustion Engine (ICE) vehicles and BEVs. This section describes these use cases which are necessary to develop ontologies to estimate the potential to save CO_2.

5.1.1 Internal combustion engine vehicles

The global automobile transportation sector accounts for almost 9% of the emitted greenhouse gases, the cause are ICE vehicles [16]. In 2022 the total transport emissions increased by 2.1%, these emissions would have been even higher without the accelerating deployment of low-carbon vehicles [13]. More efficient semiconductors make the vehicles more sustainable. Higher efficiencies directly influence the fuel consumption of the vehicle which leads to lower CO_2 emissions. The ontology containing the structure for the CO_2 emissions of ICE vehicles allows to estimate the savings through IFAG product improvements.

5.1.2 Battery electric vehicles

The fast-growing adoption of BEVs and increasingly rapid build-out of the enabling charging infrastructure present their own logistical challenges. This rapid BEV increase requires higher component capacities for its manufacturers. Thus, IFAG is expanding chip factories to research and produce energy-saving chips needed to support the rapidly expanding BEV market. The IFAG products in BEVs are the main inverter, HV-LV DC-DC converter, On-board/Off-board charger, battery management system, heater, and the auxiliary inverter. These components and their purpose in the vehicle are now further described.

Main inverter
The inverter controls the electric motor. This is a key component in electric cars as, like the Engine Management System (EMS) of combustion vehicles, it determines the driving behavior. Regardless of whether the motor is synchronous, asynchronous, or brushless DC, the inverter always functions in a similar way and is controlled by an integrated printed circuit board (PCB), which should be designed to minimize switching losses and maximize thermal efficiency. Not only does the inverter drive the electric motor, but it also captures the energy released via regenerative braking and feeds it back to the battery. As a result, the range of the vehicle is directly related to the efficiency of the main inverter.

HV-LV DC-DC converter
Different voltage levels are required by the various electronic components in a BEV. High-voltage batteries with different voltage levels are currently available on the market. In addition, the power classes scale from 1 kW to 5 kW depending on the number of low-voltage applications. In the past, the alternator was used to supply the 12 V power supply system. In BEVs, the DC-DC converter supplies the 12 V power system from the high-voltage battery. Designers are called on to increase the conversion efficiency as a way of extending the range of the vehicle. Furthermore, different components may be required depending on whether the design is geared toward a uni- or bidirectional energy transfer.

On-board charger
The battery in a BEV is useless without a battery charger. Furthermore, all electronic systems depend on the battery for power. In BEVs, the battery can be charged from a standard power outlet. Charging via the main grid calls for design flexibility due to the different voltage and current levels in different countries. And the charging time is also an important factor for car drivers. System designers face the challenge of supporting the varied voltage and current levels while increasing the power density. When it comes to on-board charging, the key success factors involve efficiency and a high-power density for a small form factor. The long-term trend is moving towards bi-directional charging, where the charger also feeds power from the car to the smart grid.

Battery management system
The battery management system (BMS) oversees monitoring each of the cells included in a battery pack and ensuring that they are operated within the safe operating range. It monitors and reacts to the State of Health (SoH), State of Charge (SoC) and Depth of Discharge (DoD) with the assistance of balancing ASICs. It is also able to operate under low-current consumption mode to ensure holiday parking. Furthermore, it prevents illegal manipulation of both the system and battery packs via integrated security on the AURIX™ microcontroller.

High-voltage heater
BEVs require heating source in their heating, ventilation, and air conditioning (HVAC) system. The high-voltage (HV) heater subsystem is interconnected to the HV battery through power switches. Due to strong cost pressure on this subsystem and high EMC requirements for the HV wire lines, the designers are challenged to achieve lowest system costs on a sufficient Electromagnetic Compatibility (EMC) level. IFAG semiconductor solutions help to optimize system costs and maximize its efficiency.

Auxiliary inverter
In BEVs, typical auxiliary systems (PTC heaters, auxiliary drives etc.) are supplied via the high-voltage battery. Notably, the devices that were formerly belt-driven (such as the e-compressor for HVAC systems, oil pumps and cooling pumps) have now been electrified and integrated into the power system. These auxiliary inverters now deliver power on demand, thereby increasing the vehicle’s energy efficiency. As power from the battery is expensive, the challenge is to use the electric power as efficiently as possible.

Demand for BEVs continues to rise. These vehicles are packed full of power electronics – most of which are currently based on silicon. However, the latest BEV designs call for advances in efficiency and power density. Silicon carbide (SiC) is emerging as the material of choice for overcoming the performance plateau of silicon. Highlights such as low switching losses, a high temperature capability and high switching frequency make it ideal for meeting the highest BEV requirements. SiC-based solutions promise to be more efficient, compact, and lighter than conventional applications.

5.2 Renewable energy technology

Renewable energy technologies have the potential to meet the rising energy demand and reduce carbon emission at the same time. Political regulations embrace sustainable energy generation technologies such as solar photovoltaic and wind turbines, therefore, they can play key roles in the CO_2 emissions of the local energy mix. A low carbon energy mix lowers the CO_2 footprint of electric vehicles and other electricity consumers.

IFAG is one of the largest semiconductor suppliers for renewable energy technologies [14]. Thus, the semiconductor solutions assist in the sustainable energy transition bringing more wind and solar power into the energy mix. Additionally, IFAG delivers other electronic components for the energy conversion chain. In 2019 IFAG products avoided the emission of about 76 million tons of CO_2 emissions [15].

5.2.1 Solar photovoltaic

PV systems are one of the most demanded applications to address carbon reduction and increase the share of renewable energy in the grid. However, one of the biggest challenges facing the renewable sector is the need to balance supply and demand. The power supplied by photovoltaic (PV) modules fluctuates heavily depending on weather conditions. Nevertheless, the challenge of quitting fossil energy sources can be achieved with smart grid management and an energy storage system. PV panels supply power in the form of direct current (DC), which has to be converted to alternating current (AC) before it can be fed into the grid and consumed locally or transmitted to the point of use. Solar inverters convert DC to AC.

Efficient and reliable power semiconductors and inverter technologies are required to convert DC to AC and transmit the power with minimal losses. Combining solar systems with energy storage systems is one effective way of synchronizing supply and demand. IFAG's portfolio comprises a broad selection of components to build inverters ranging from just a few watts and kilowatts for residential use to several megawatts for the commercial and utility-scale markets [17]. IFAG products effectively increase energy efficiency of the PV technology reducing the CO_2 lifecycle footprint of PV power plants.

5.2.2 Wind turbines

In wind turbines, power semiconductors convert electricity and couple the generator to the grid. A wind power converter in a wind turbine controls several essential functions apart from transferring power and therefore requires power semiconductors of the highest quality. Wind turbine designs must provide maximum availability to contribute to grid stability. Grid stability, therefore, depends on power semiconductor devices that offer dynamic capabilities, excellent functionality, and superior reliability.

IFAG's power module supports a wide range of activities in the wind turbine nacelle during efficient wind power generation: feeding the generated electricity into the grid, ensuring grid stability, aligning the wind turbine and the rotor blades with the wind, protecting the wind turbine from overheating, or freezing and shutting down the wind turbine in an emergency [18]. IFAG products effectively increase energy efficiency of the wind turbine technology reducing the CO_2 lifecycle footprint of wind turbine power plants.

6. CO_2 Burden of the internal supply chain

This chapter intents to provide examples for potential ontologies that can be merged to the digital reference to determine the internal supply chain CO_2 emissions. First, the supply chain transportation is displayed in an ontology discussed in the WP4 kick-off workshop. Followed by information's on determining the emissions of the IFAG plants in different locations. The objective is to identify and categorize various contributors to emissions, encompassing energy consumption patterns, transportation, and manufacturing processes. By dissecting these sources and categories, valuable insights into the environmental impact of IFAG's internal supply chain operations can be gained, enabling the formulation of targeted strategies for emission reduction and sustainability enhancement.

6.1 Transportation in the supply chain

IFAG is a global company that operates in multiple countries and serves customers around the world. As such, transportation is a critical aspect of its business operations. According to IFAG's 2022 sustainability report [19], the company emitted approximately 123,376 tons of CO_2 equivalent from both internal and external transportation activities and 24,872 tons of CO_2 equivalent in travel activities in 2022. These emissions are mainly associated with the transportation of goods, materials, and people to and from our facilities, as well as business travel by our employees. There are several reasons why IFAG's transportation activities result in significant emissions. One is the sheer volume of transportation required to support our global supply chain and customer base. As a manufacturer, we rely on a vast network of suppliers and distributors to deliver the materials and components needed to produce our products, as well as to transport finished goods to customers around the world. This involves a substantial amount of shipping, trucking, and air travel, all of which generate emissions. For IFAG air fright is the most relevant CO_2 emission supply chain transportation mode.

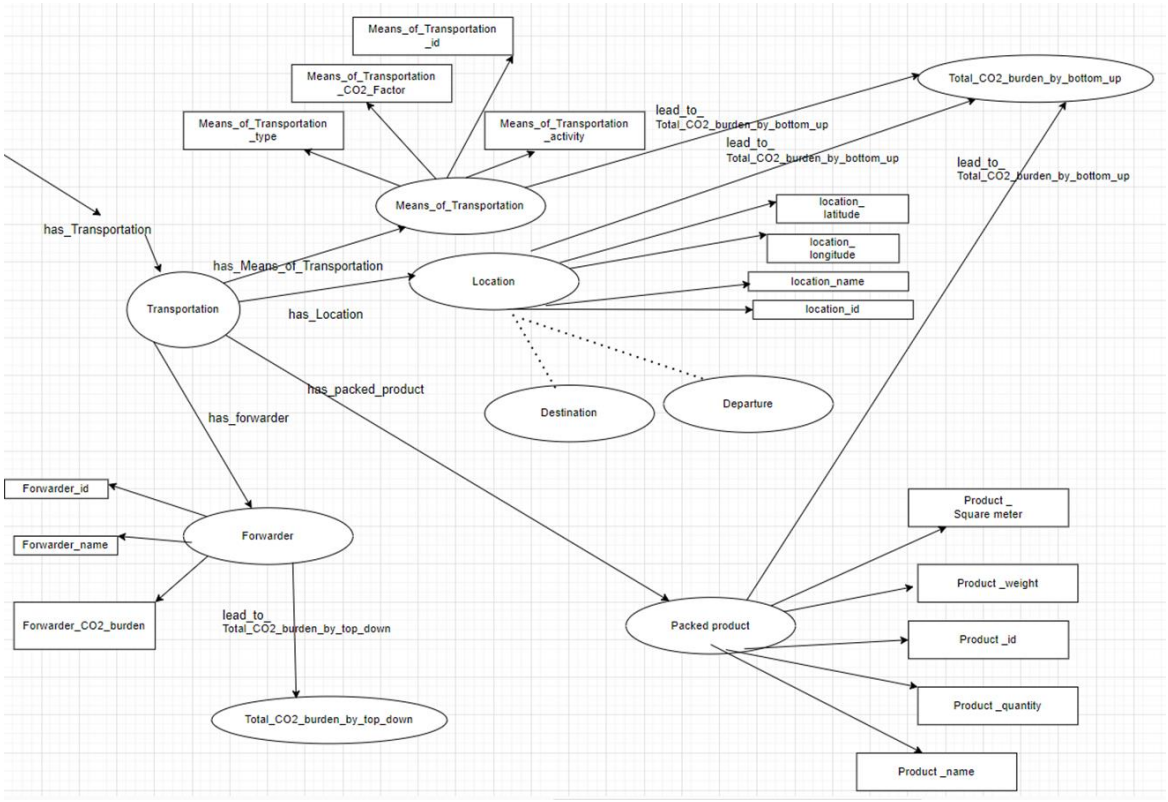

Figure 8: Scope3 emissions for transportation drOWLing.

Figure 8 shows an example of a drOWLing on how the Transportation CO_2 footprint for IFAG can be determined. These Scope3 emissions are divided into external transportation emissions that are forwarded from the suppliers, and transportation that is organized within the company. The external transportation requires the supplier to provide the knowledge of how much CO_2 was generated to provide the requested service. More details on sustainability in the external supply chain will be discussed in the next deliverable.

To determine the internal supply chain transportation CO_2 emissions the knowledge of the weight of the freight, distance covered and the CO_2 emissions the transportation mode generates while operating are required. The Ontology in Figure 9 (see next page) provides the structure to determine the total transportation CO_2 footprint. With the necessary data of all the transports summed up the total CO_2 emissions for transportation can be determined.

Like this Transportation example different ontologies of all the individual elements generating GHG emissions can be created and integrated into the DR to determine the total CO_2 emissions from scope 1 to 3.

6.2 CO_2 burden of the manufacturing locations

The explained concept finds its primary application within WP4 of the AIMS5.0 project. WP4 strives to establish a consistent and modular semantic description of industrial domains and supply chains using the Digital Reference ontology. The goal is to develop an Open-Access Platform (OAP) for maintaining and accessing this description, supporting ontology learning, validation, and manual post-processing. In charge of this work package are Infineon, DAC.digital, Fern Universität Hagen and NXP Semiconductors. Within this context, the DR plays a crucial role as a sustainable foundation for the OAP.

The focus of the DR extension is set mainly on the production sight. Therefore, the aim is to find a measurement which shows how sustainable manufacturing is. To calculate the CO_2-burden of each FE and BE location the total facility electricity consumption is used. This approach is reliable because the CO_2 burden of the energy generation processes in the different locations is assessable. There are many ways to produce green electricity without any operational CO_2-burden, two of them were introduced in the chapter 5.2 e.g., Wind Turbines and solar PV. To break this further down the available data to measure CO_2-burden per manufacturing site at IFAG is the total electricity consumption. Moreover, this data also correlated with the source of electricity. Therefore, it is directly visible which electricity consumption has CO_2-burden and which is green electricity with zero emission. To extend the DR with the explained method, the sustainability lobe is used. If the project frame allows a smaller data granularity, such as data from the individual process steps, a more detailed CO_2-burden breakdown can be achieved. However, this type of data is currently not accessible.

Figure 9 displays the status of the domain with the total electricity consumption for FE and BE manufacturing. The current Digital Reference will be expanded by creating additional classes to accommodate the use cases explained above. Following classes will be added: FE manufacturing location, BE manufacturing location, product types, wafer diameter, electricity consumption. To show the connection between the current DR and the newly added classes Figure 10 is used. That Figure visualize just a snapshot of the DrOWLing.

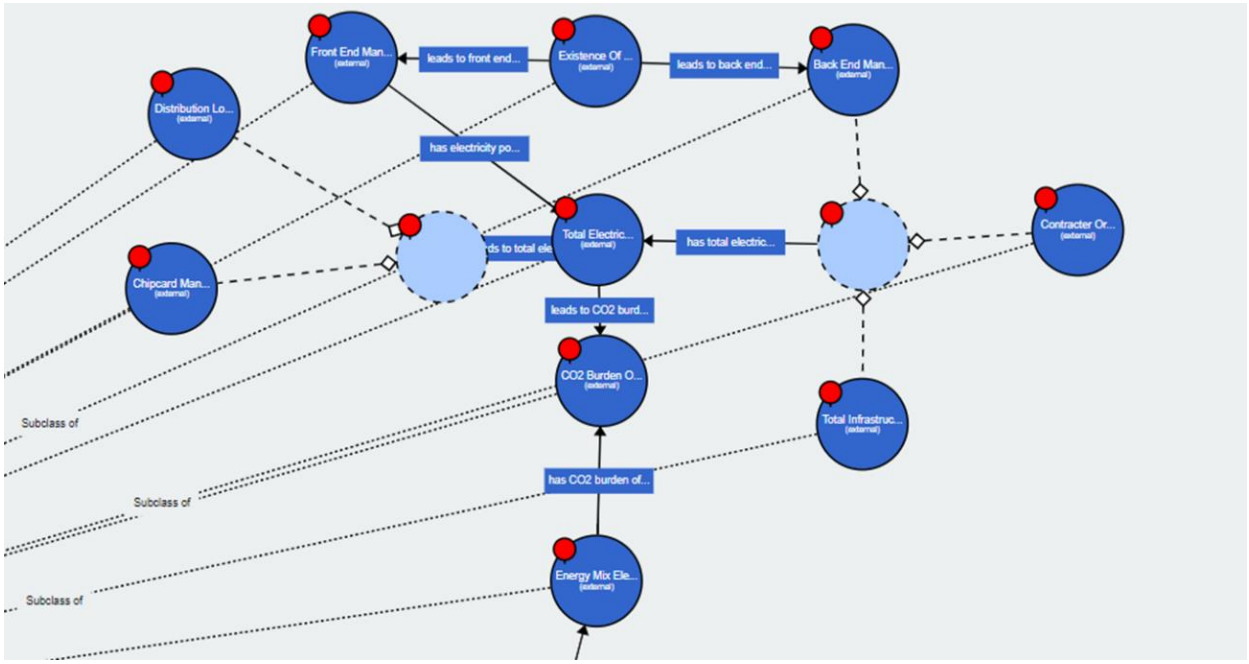

Figure 9: Total electricity consumption ontology.

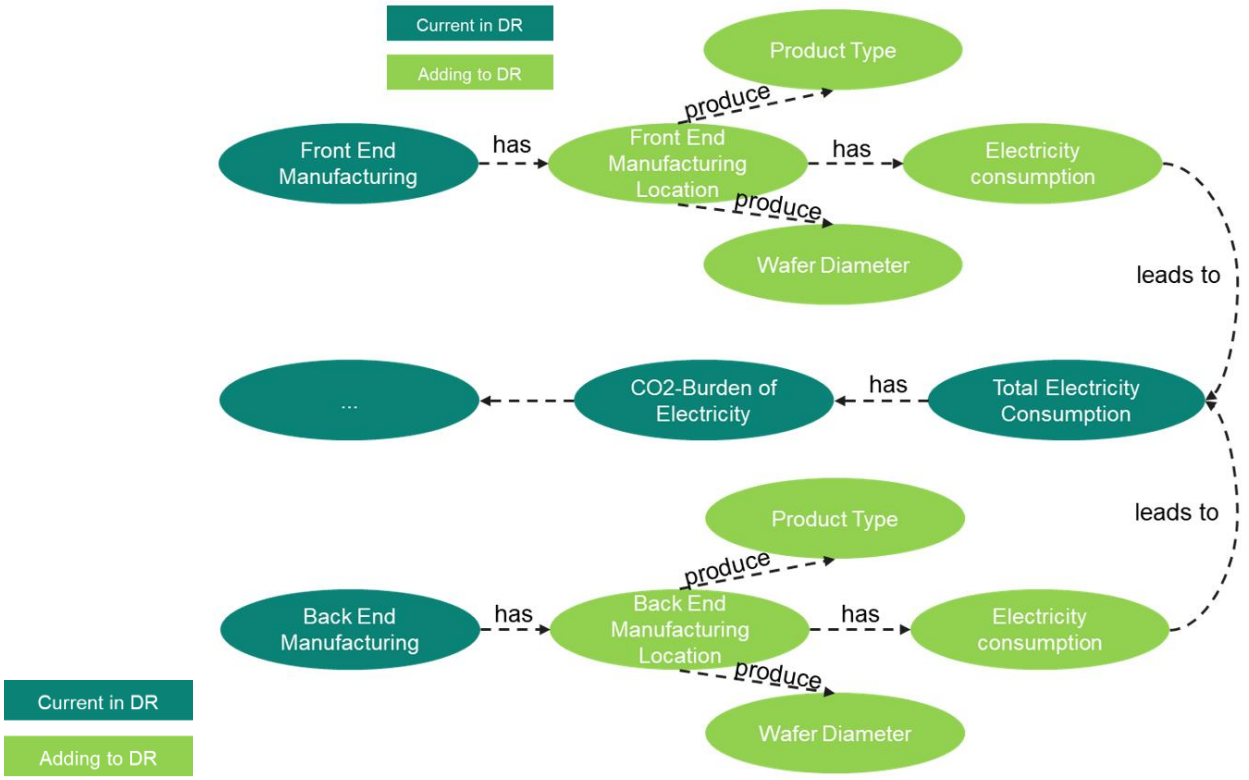

Figure 10: Extension to the DrOWLing.

With these newly added classes and properties it is possible to measure the total electricity consumption and the CO_2-burden per location. Moreover, total electricity consumption is split into green electricity consumption and electricity consumption. This directly shows the CO_2-burden of the used electricity per location and the amount of CO_2-savings through the green electricity consumption. As a result, the extensions to the DR enable to determine the CO_2-burden of the electricity consumption. This allows to get a better understanding of these CO_2 emissions and take action to reduce the emissions.

7. Conclusion and outlook

This deliverable addresses the topic of determining the internal supply chain GHG emissions. Following IFAG's overall aim to become net-zero by 2030, it is imperative to find the emission contributors necessary to create a sustainability strategy aiming for net zero emissions.

The goal of WP4 is to develop an Open-Access Platform (OAP) to maintain and access a consistent and modular semantic description of industrial domains and supply chains using the Digital Reference ontology. Thus, the OAP provides the architecture to enable seamless data exchange for an efficient and straightforward collaboration of the project partners and other users. Various purposes to share knowledge graphs and data, view the DR, edit knowledge graphs, and query and download data are facilitated.

The document describes ontologies that enable to determine the CO_2 emissions that can be saved through the improvement of IFAG products in different use cases such as conventionally powered and battery electric vehicles, solar PV technology and wind turbines. Additionally, topics such as internal and external transportation are introduced to be added to the DR. Furthermore, IFAG sustainability analyses show that the CO_2 emissions vary depending on the location of the IFAG facilities with different local energy mixes. Thus, ontologies breaking down the important variables to analyze the CO_2 footprint of different locations can provide valuable results. Ontologies integrated in the DR provide the framework to determine the GHG emissions in a structured manner to investigate the goals of the AIMS 5.0 project.

Future work should focus on a smaller data granularity, such as data from the individual process steps, to allow for a more detailed CO_2-burden breakdown. Additionally, the data from the external supply chain should be analysed and discussed to extend the DR and CO_2 emission estimation further.

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9. Appendices

9.1 Appendix A - Abbreviations

Table 1: Abbreviations

Abbreviation	Meaning
AC	Alternating Current
AIMS5.0	Artificial Intelligence in Manufacturing leading to Sustainability and Industry5.0
BE	Back End
BEV	Battery Electric Vehicle
BMS	Battery Management System
DC	Direct Current
DoD	Depth of Discharge
DR	Digital Reference
EMC	Electromagnetic Compatibility
EMS	Engine Management System
FE	Front End
GHG	Greenhouse Gas
HV	High voltage
HVAC	Heating, ventilation, and air conditioning
ICE	Internal Combustion Engine
IFAG	Infineon Technologies AG
NF3	Nitrogen trifluoride
OAP	Open Access Platform
OWL	Web Ontology Language
PFC	Perfluorinated compounds
PCB	Printed circuit board
PV	Photovoltaics
R&D	Research & Development
RDF	Resource Description Framework
SCOR	Supply Chain Operations Reference
SF6	Sulfur hexafluoride
SiC	Silicon carbide
SOC	State Of Charge
SoH	State of Health
pWP4	Work Package 4
XML	Extensible Markup Language