“Designing for Carbon Neutrality”

Activities of the Green CPS Consortium for sustainable manufacturing

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1. Introduction

As we all know, a business strategy to sustain the global environment is the biggest and most urgent challenge we face. Social management of the entire economic activity toward decarbonization beyond individual organizations, using IT and data infrastructures, is an effective approach toward this goal. What we need to do now is to control the efficiency of the entire economic activity through mutual cooperation among organizations in order to reduce the various losses that occur while promoting economic growth.

To address these social issues, we established the Green CPS Consortium as a general incorporated association in June 2022. The Green CPS Consortium focuses on the potential of cyber-physical systems (CPS) and data sharing, and promotes the social implementation of new systems that utilize process simulation and AI to optimize the entire organization.
This paper introduces our activities toward carbon neutrality.

2. Toward a sustainable society and industry

The Consortium is working diligently on activities toward carbon neutrality. We are also working on the following three initiatives: (1) to obtain evaluation indices for GHG (greenhouse gas) emissions by utilizing advanced process simulation technology, (2) to accumulate GHG emissions data for data compilation and mutual use, (3) to construct an operational system to promote the overall optimization of GHG emissions by integrating and linking various organizations and business categories, and (4) to promote individual behavioral changes in the organizations involved. In addition, we are promoting an educational system that encourages individual behavior change and promotes awareness reform in the organizations concerned (Figure 1).

On the other hand, individual activities of each organization alone cannot achieve Lean

(reduction of waste) in the industry as a whole. It is effective to connect management and the field, and to design the ideal form of the entire system by linking different business processes, and then to optimize collaborative activities by utilizing CPS. The CPS will explore the possibility of realizing a Well-Being society by balancing environmental issues and growth potential, starting with "designing carbon neutrality".

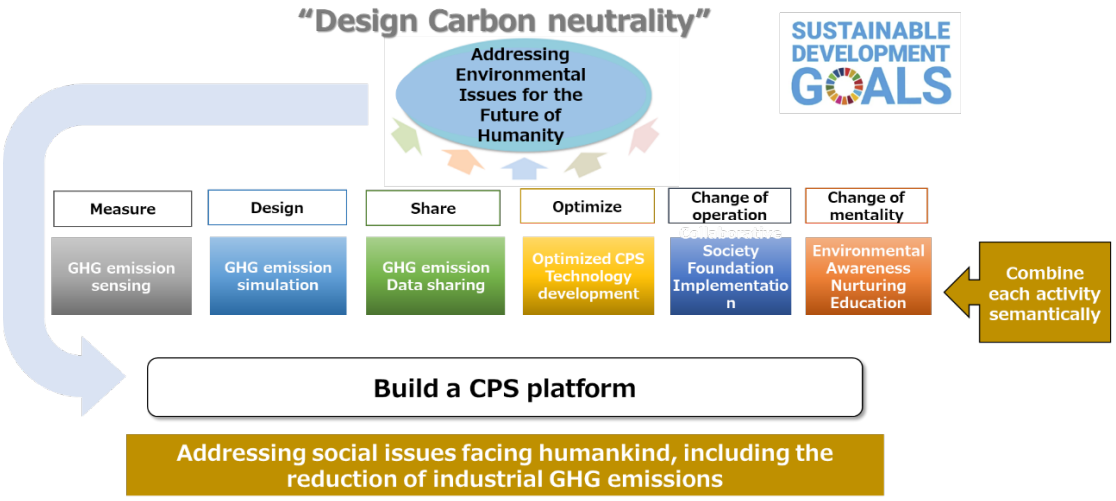


Figure 1: Concept of the Consortium

3. Current challenges in environmental issues

This section will review the current challenges to environmental issues. First, environmental issues that must be addressed urgently are a "cost" from a managerial perspective, and streamlining and reforming operations to address these issues is just the beginning. Second, in the trend toward disclosure of CO2 emissions, companies themselves need to restructure themselves to strengthen their competitiveness by questioning their own value, as well as their procurement selection. In the midst of this movement, grand designs and optimization methods are required to determine not only how to calculate CO2 emissions, but also how to reform business operations and organizational management with an eye toward the future (Figure 2).

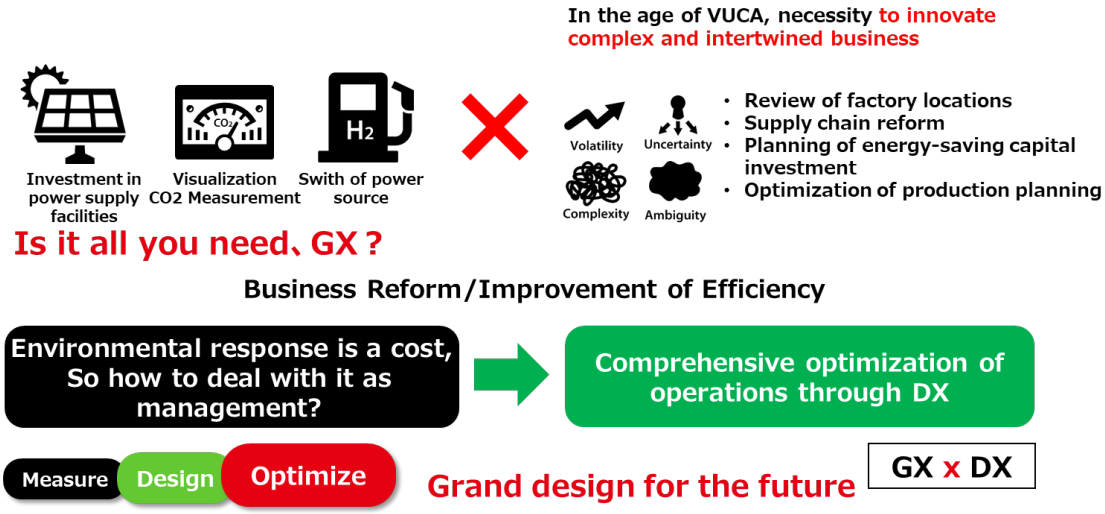


Figure 2: Current issues in environmental issues

4. Management's dilemma regarding environmental issues

As already explained above, the promotion of environmental management strategies toward carbon neutrality is, in many ways, a "must-have" issue. While measures such as the introduction of energy-efficient equipment and energy conversion are progressing, the response in terms of business processes is centered on environmental impact assessments based on GHG emissions calculations from a macro perspective, such as "consumption and loss of goods and electricity. Of course, the calculation and disclosure of GHG emissions is an important first step in today's ESG management, but from the standpoint of corporate management and production sites, it is currently seen as a social responsibility and cost (Figure 3). This is the current situation.

This is due to the fact that the current GHG emissions calculation is mainly based on secondary data, which is based on the quantity of materials constituting the product, and does not directly lead to process reform activities to formulate future strategies. From now on, it is necessary to conduct evaluation based on CFP (carbon footprint) including the supply chain and design how to change the execution organization within this large scope. In other words, in addition to QCD, it is important to pursue corporate value by conducting evaluations from the perspective of EQCD, which includes environmental assessment from the production process viewpoint.

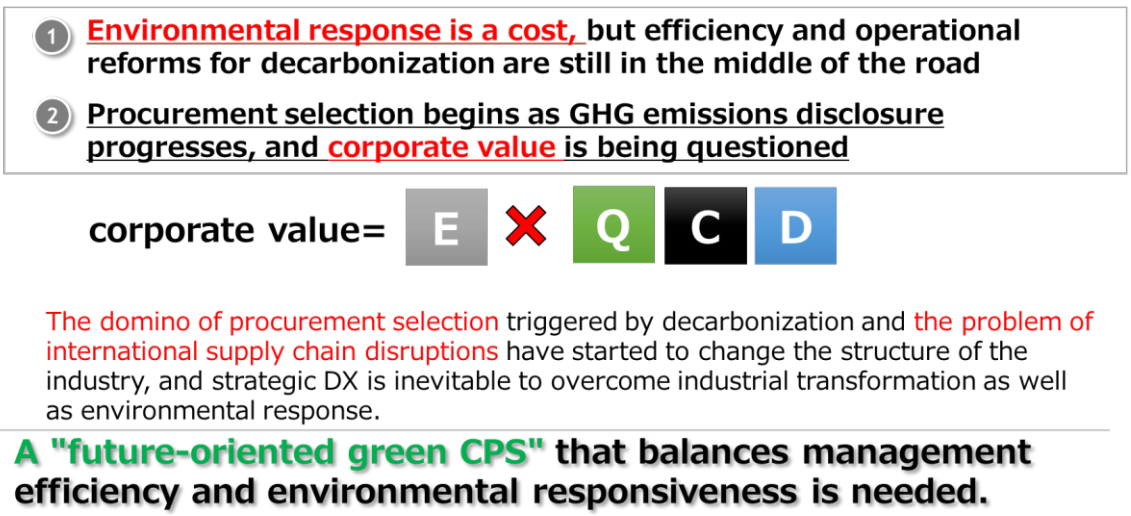
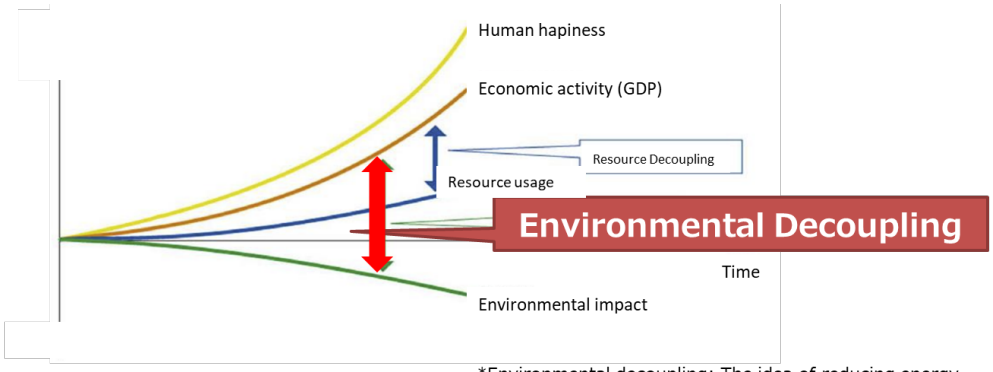


Figure 3: Dilemma of the management

5. Environmental decoupling

The United Nations Environment Programme (UNEP) has proposed the concept of "environmental decoupling" to address the compatibility of environmental issues and economic efficiency, which are considered to be in conflict with each other. The United Nations (UNEP) has proposed the concept of "environmental decoupling," in which energy consumption is thought to increase in proportion to economic growth, but energy consumption can be reduced while maintaining a certain level of economic growth and convenience, in other words, the two can be "decoupled" (Figure 4). For example, environmental decoupling can be achieved by reusing and recycling resources, changing the energy-intensive industrial structure, and saving energy in unprecedented ways.

In fact, through environmental activities, developed countries such as France, Sweden, and Canada have succeeded in reducing greenhouse gas emissions while maintaining high economic growth (Figure 5). Unfortunately, Japan is the only developed country that has not experienced economic growth and has not reduced greenhouse gas emissions. Since other developed countries can achieve this, it should be possible for Japan to achieve it as well.



Added to United Nations Environment Program (UNEP)

Environmental decoupling: The idea of reducing energy consumption while maintaining economic growth and convenience, in other words, making the two "separate" (United Nations UNEP)

Fig.4: Environmental decoupling

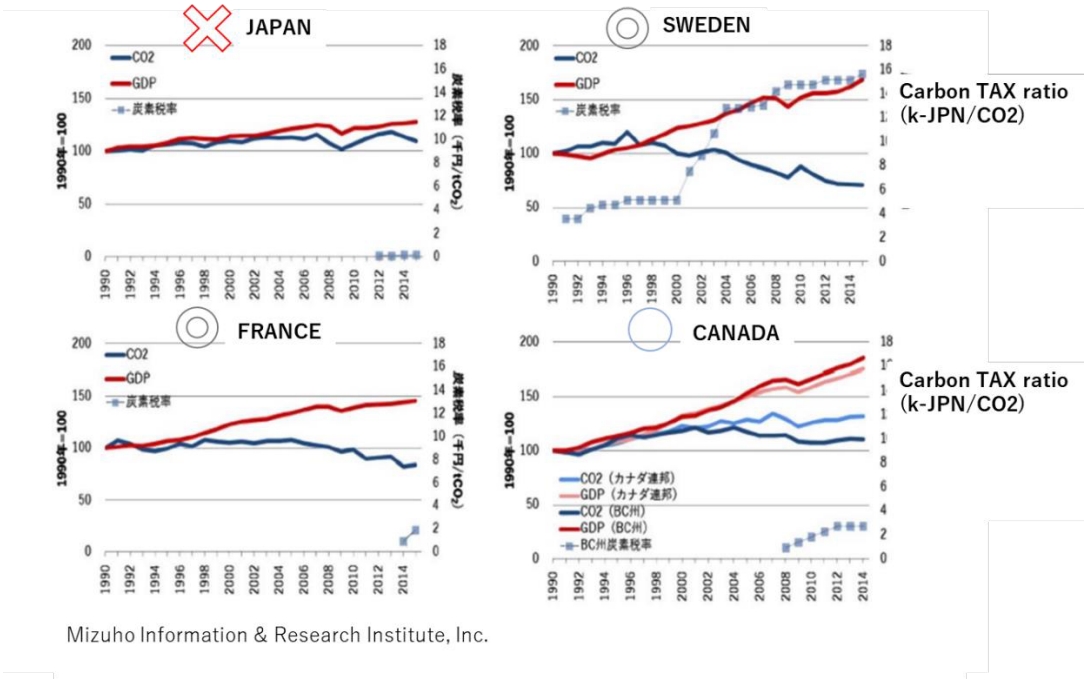


Fig. 5: Status of environmental decoupling in advanced countries

6. "Designing for Carbon Neutrality"

In order to cope with the current situation, it is important to promote approaches such as the introduction of green equipment and energy switching, as well as to reform the operation and management methods of business operations. In addition to calculating CFP, it is necessary

to design the entire business system to be carbon-neutral and to optimize business operations with a cyber-physical system (CPS) (Figure 6).

Here, the improvement of productivity through worksite reforms and kaizen, which is one of the strengths of Japanese manufacturing, will directly lead to a reduction in product CFP. In other words, one of the effective measures to be taken is to position the production innovation that has been promoted so far as an activity to address environmental issues. As mentioned earlier, we are entering an era in which CFP is required to be calculated for each product, so it will be necessary to switch from secondary data based on conventional statistical values to primary data based on measurements of each product, and this is exactly what we will be dealing with in the future.

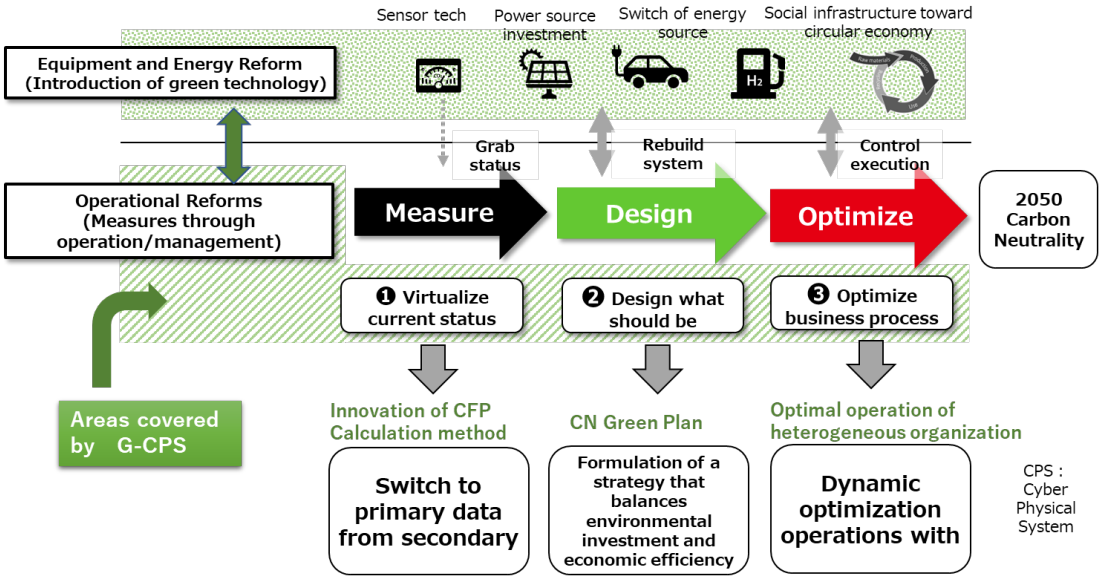


Figure 6: Designing carbon neutrality

7. From secondary data to primary data, from evaluation to process reform

As mentioned in the previous section, the conventional CFP calculation method based on secondary data is dominated by physical quantity, which leads to various inconsistencies such as double counting and the inability to reflect the upstream effort in the downstream in the CFP calculation in the supply chain, etc. The ISO 14067 and GHG Protocol (WRI and WBCSD: World Business Consortium for Sustainable Development), CDP (Carbon Disclosure Project), Pathfinder Framework (WBCSD), and other organizations provide guidelines from their respective perspectives. However, it is difficult for the industry to

understand and comprehend them, and it is also hard to deal with them because their goals are not absolutely defined. On the other hand, the understanding of the problem of using secondary data is consistent, and all the guidelines indicate that the primary data should be used.

Taking the production of hamburgers as an example, the CFP calculation method using secondary data is a method in which the CO2 emissions intensity of the component types such as bread, tomatoes, lettuce, bread, etc. that constitute the hamburger are multiplied by their weight (Figure 7 left). In this case, even if upstream suppliers make efforts to reduce CO2 emissions, their efforts are not reflected to downstream users. In addition, the reuse of component parts in a circular economy system can double-count CO2 emissions, and the CO2 emission reduction effect of downstream (user-side) use of products with improved energy efficiency is not reflected downstream. Furthermore, since a method of substituting value-added instead of weight is now allowed, we must solve structural problems that do not reflect the original decarbonization activities of each company.

To address these issues, regions and organizations that are leading the way in environmental response are beginning to recommend a shift to a primary data method that builds up processes. The CFP calculation for the production of a certain product is based on the processes involved in that product. In the case of a hamburger, as shown in Figure 7 on the right, to produce a hamburger, a bun is cut, meat is baked, and then tomatoes, lettuce, and ketchup are added to make the product. Furthermore, the energy consumption in logistics related to the procurement of the materials used in the process, and the manufacturing process of bread, ketchup, and other materials are also added up.

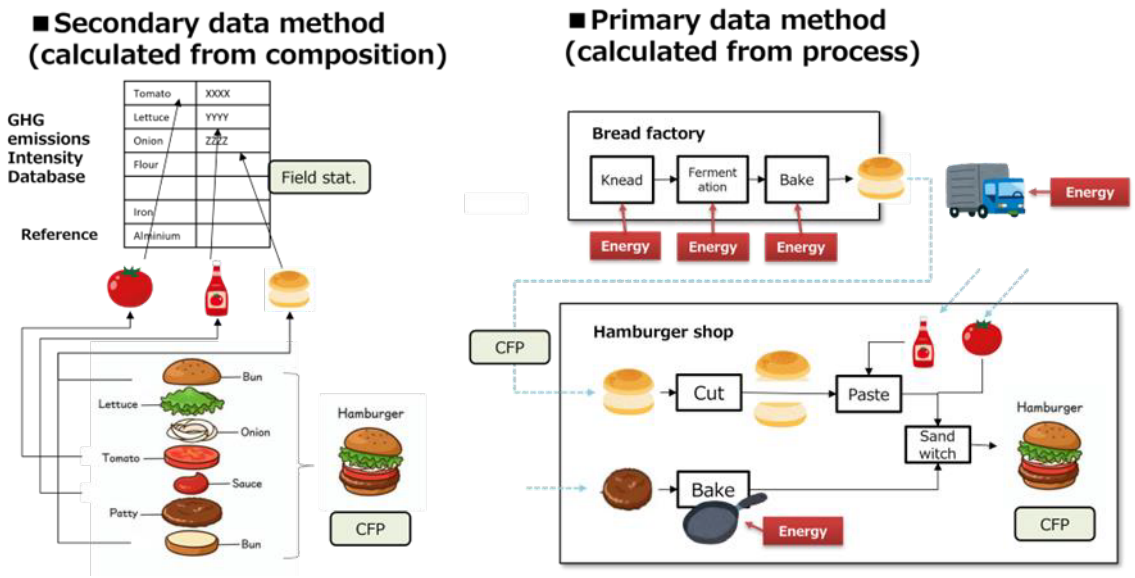


Fig.7: From primary data to secondary data

This concept can be expressed in the case of the manufacturing industry as shown in Figure 8.

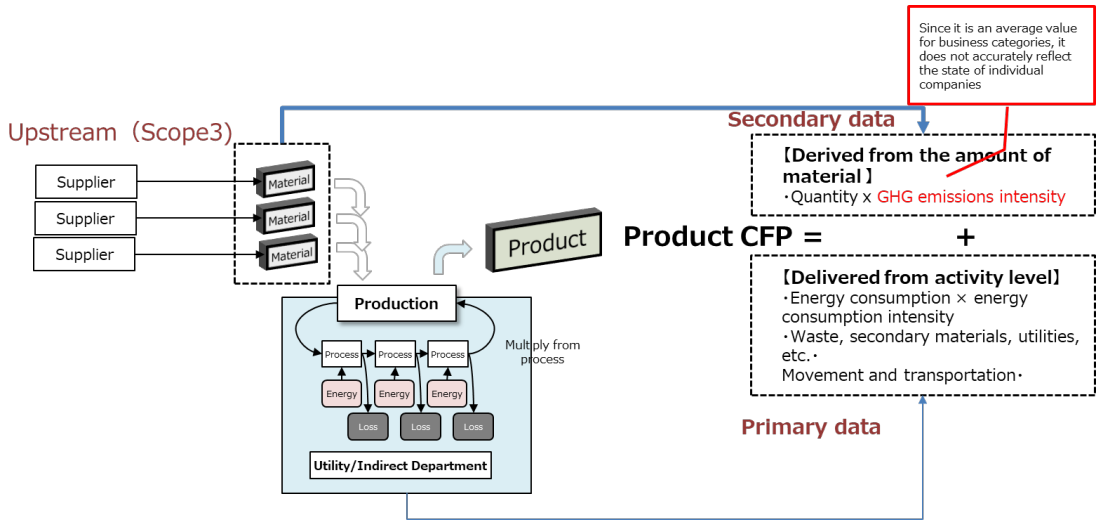


Fig. 8-1: Secondary data method for the manufacturing industry

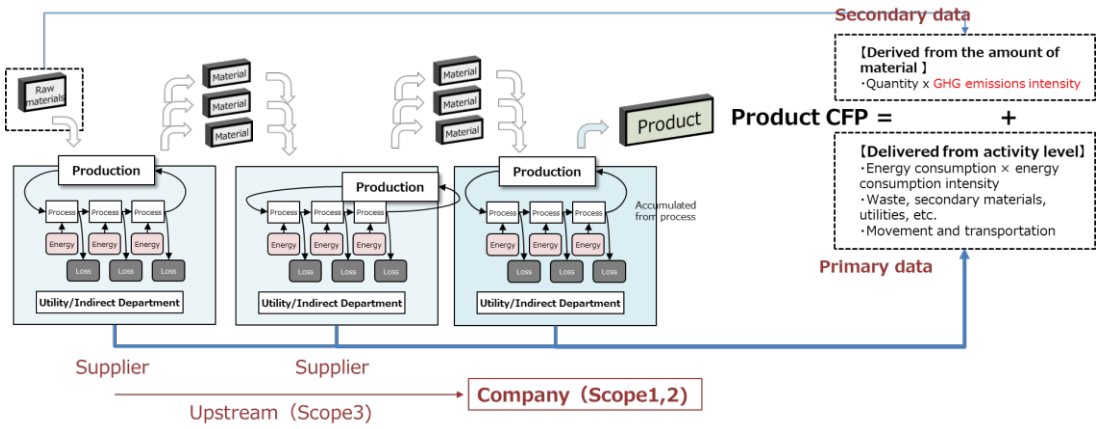


Fig.8-2: Primary data method for the manufacturing industry
(Scope 3 primary data conversion)

This method of accumulating primary data is recognized as a "purer method" in the Scope 3 calculation, and is recommended in ISO and METI guidelines (see below) to increase the ratio of primary data in Scope 3 as the primary data share (PDS). The intention is to increase the ratio of primary data in Scope 3, which is recommended in ISO and METI guidelines. The intention is that this approach will promote decarbonization activities because it will lead to an assessment of the role and contribution of each business.

As you know, one of the effective measures to achieve the Science Based Target (SBT) agreed in the Paris Agreement is not only to set targets but also to develop future measures. In this movement, the soil for carbon neutrality as a process reform is being fostered, and it is thought that a situation will develop where sustainable manufacturing can be tackled from the viewpoint of the production system centered on the production process. Environmental responses, which were previously positioned as a social responsibility, are now being viewed as part of the production system and organizational management. On the other hand, the issue is that it is necessary to trace the flow of each product as primary data, and a method to deal with this is required. The measures to deal with this issue will be described later. 8.

8. Promotion of GX by DX

In response to the evolution of the CFP calculation method, the Consortium proposes a method to express the behavior (business process) rooted in the business activities of an organization on a computer through "production system simulation" and to develop it into

business reform activities by analyzing activities through estimation of activity volume. We believe that building a platform that directly links on-site activities and management and reflects them in environmental strategies is one of the most meaningful approaches.

We do not make any special preparations for CFP evaluation, but rather, we are conscious of making it possible to conduct CFP evaluation based on current business information and to simultaneously calculate economic indicators (productivity, manufacturing cost, inventory, lead time, etc.) for pursuing economic rationality by using production simulation, so that activities can be conducted from the viewpoint of the field. The method is designed to enable activities from a shop-floor perspective. By simultaneously evaluating economic efficiency and environmental impact, which have a trade-off relationship, it is possible to develop management strategies from multiple perspectives (Figure 9). In other words, it is to promote the realization of GX, which is called environmental decoupling, through DX, which is called operational reform. The Consortium aims to develop and promote a framework that contributes to GHG reduction through the consolidation and advancement of each participant's knowledge, its dissemination, and its mutual utilization.

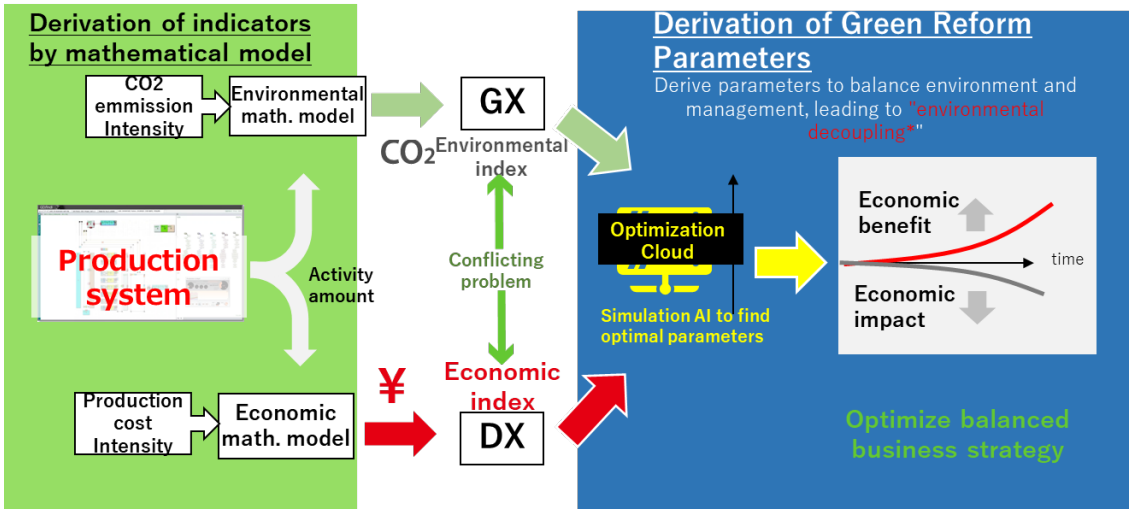


Fig. 9: GX (environmental decoupling) by DX (operational reform)

9. Improving efficiency of primary data calculation by production system simulation

As described in Section 7, "From Secondary Data to Primary Data, from Evaluation to Process Reform," while the primary data method is required, it is necessary to trace the

production process and logistics for each product to realize it, which forces a highly difficult operation. In fact, as shown in Figure 10-A, the conventional calculation method is to measure the energy of the entire organization, such as the power board at the source of a certain factory, and divide it proportionally by the type and quantity of production items. On the other hand, the best method required by the one-data method is to measure the activity power, i.e., energy consumption and resource consumption activity, for each production process (facility), and accumulate and add up each obtained for each product (Figure 10-C). Although this method is ideal, it is needless to say that it is very difficult to realize it by installing sensors in all processes and collecting actual data. Therefore, we recommend a practical method to obtain primary data with higher purity.

As shown in Figure 10-B, this method uses data from a small number of actual measurement points to estimate the amount of activity in the entire production process. Each manufacturing company basically has information such as BOM, BOP (bill of materials), and process design of production lines as manufacturing basic units to produce products. Using this information, a "production system model" is prepared and then a production simulation is conducted. Since the production simulation can analogize the flow of goods and the amount of activity in all processes, this output is used as the primary data. In other words, it is a method of calculation based on a hybrid of partial actual measurement and virtual factory after virtualizing the production system, and is recognized as a method of reusing analogous data in ISO 14067. This concept is recognized in ISO 14067 as a method of reusing analogous data. This method is considered to be realistic as a simple, rational, and efficient method of making better calculations in the actual operations of each company.

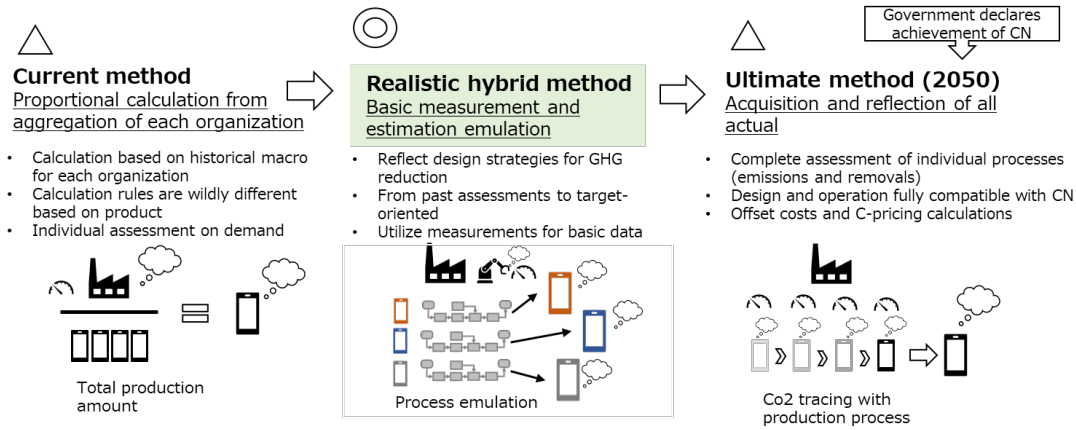


Fig. 10: Future CFP calculation method based on primary data

In fact, in the EU and other countries that have taken the lead in CFP calculation, a method that calculates CFP by estimating the behavior of the production system with a logic model has begun to spread. Figure 11 shows the method realized by BASF of Germany, which automatically calculates CFP for a huge number of products by using a database such as ERP related to production and a logic model to calculate CFP for each product. The key point is how to utilize such a rational method in many companies, including not only large companies but also small and medium-sized enterprises (SMEs). In this case, small and medium-sized companies may find it easier to introduce CFP because the number of processes is shorter than that of large companies. In the case of Scope 3 mentioned above, the calculation of primary data by SMEs, which are located upstream of production, is important, and the spread of such a method will lead to the strengthening of manufacturing in Japan.

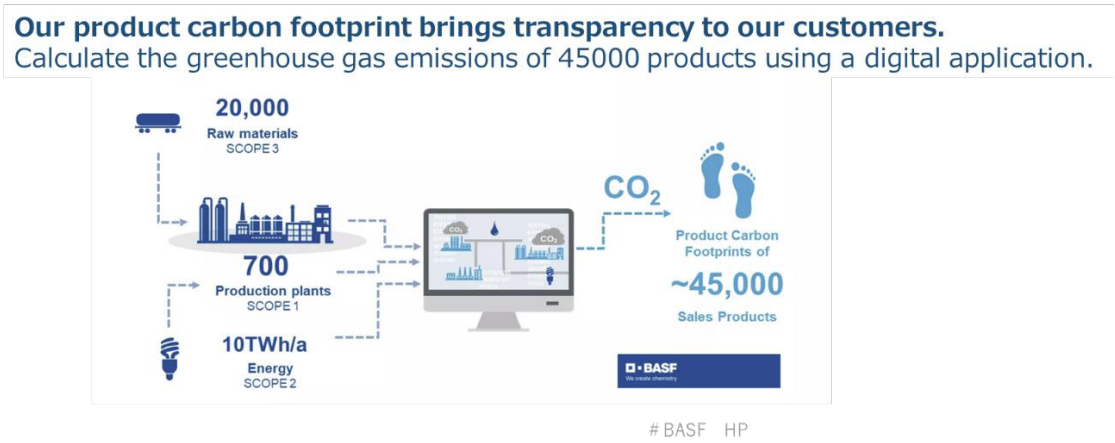


Fig. 11 : Example of CFP calculation system for each product based on a logical model (BASF, Germany)

10. Systemization and optimization of CFP calculation for products by digital twin

In order to promote the ideas introduced above, it is an issue how to promote and implement the hybrid calculation of DX and GX, as well as the hybrid calculation in virtual factories. For this reason, the Consortium is promoting the idea of promoting production innovation while systematically calculating product CFP by introducing the digital twin (CPS: cyber-physical system) as one of the methods.

As shown in Figure 12, the production line in a physical factory is considered as the physical layer, and the production line virtualized on a computer is considered as the cyber layer. The

activities on the cyber side can be captured for each order in units of materials, parts, and products, enabling the systematic calculation of highly accurate product CFP based on the amount of activities obtained here. Although the granularity of modeling, determination of inventory and boundary, and synchronization level of digital twin certainly affect the quality of CFP calculation, it is a realistic method that can be implemented at low cost in terms of labor, quality, speed, and repeatability for the CFP calculation based on primary data. However, in the case of CFP calculation using primary data, it is a realistic method that can be implemented at low cost in consideration of labor, quality, speed, and repeatability. The Consortium will promote activities to promote social implementation by making the best use of such DX.

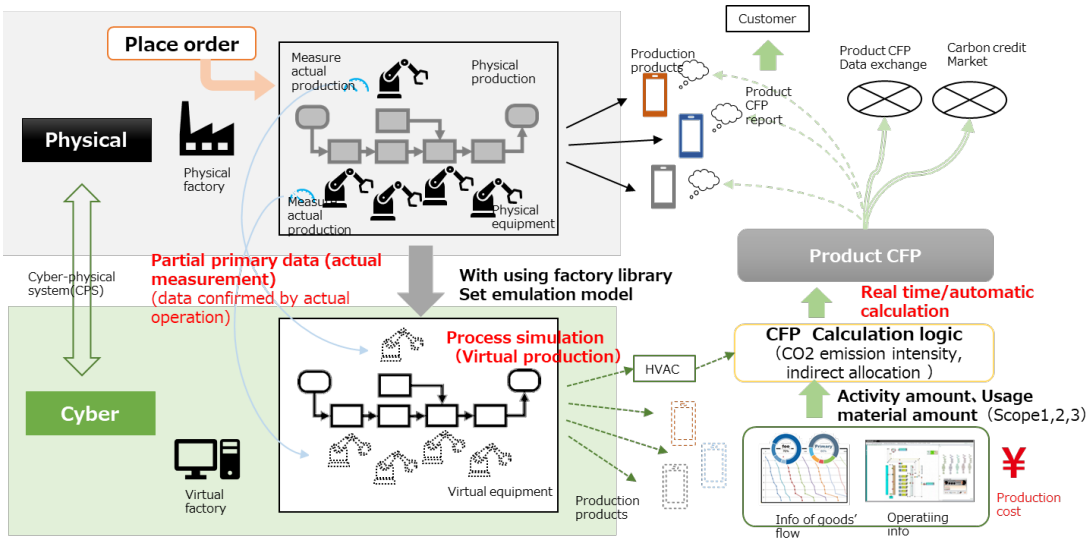


Fig. 12: Systematic calculation method of product CFP by digital twin (CPS)

11. New guidelines for CFP calculation issued by METI (Ministry of Economy, Trade and Industry)

With such emphasis on process management, various operational frameworks centering on CFP calculation are being developed, such as green procurement, CFP disclosure as supplier engagement, and regulations utilizing CFP. In particular, the Carbon Border Adjustment Mechanism (CBAM, so-called border carbon tax) and battery market access restrictions (i.e., import restrictions) are scheduled to be implemented starting from Europe, which has been making progress in environmental measures, and METI plans to issue guidelines on CFP calculation in March 2023 to respond to these plans. For this purpose,

METI established the "Study Group on Calculation and Verification of Carbon Footprint toward Carbon Neutrality in the Entire Supply Chain" in September 2022, and has been working on formulating guidelines for CFP calculation based on primary data. The Consortium has been invited as a member of this committee, and has been discussing the establishment of guidelines for CFP calculation.

Figure 13 shows one of the guidelines for CFP calculation provided in the guidelines. It is recommended that the ratio of primary data with higher purity and accuracy be increased in the calculation of CFP, and that objectivity be enhanced by using highly objective criteria in accordance with the product-specific calculation rules. In the figure, the method described in the previous section is recommended because the upper right is positioned as the better method. The Consortium will promote activities to support calculation methods based on this primary data method and optimization based on it.

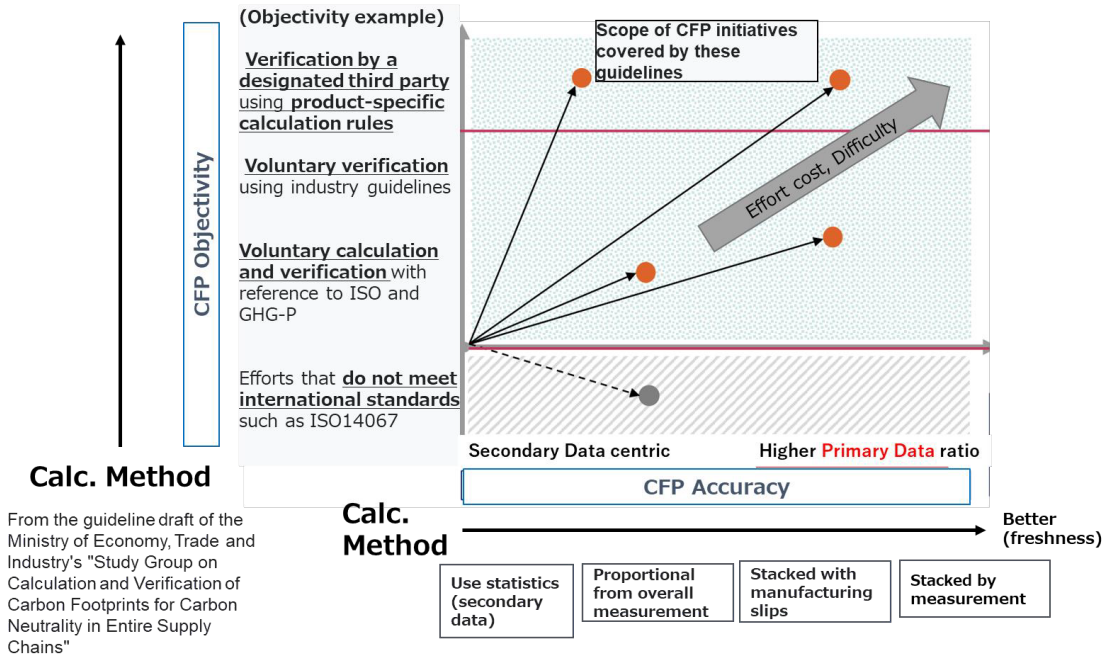


Fig. 13: Concept of guidelines for CFP calculation

12. Beyond CFP calculation - Application and Development of the CPS platform

In addition to "designing toward carbon neutrality," the Consortium will also work on social systems to optimize and implement such a design. We will link various systems on the CPS platform provided by the Consortium to form a digital twin and promote the construction of applied applications (Figure 14). We will discuss the use of CPS for overall optimization by

linking heterogeneous organizations with data models, and aim to apply this platform to various fields and implement it in society. Here, we start with the implementation of advanced manufacturing systems such as industrial metaverse, and aim to apply it to social areas such as circular economy, supply chain, and even smart cities. We also provide support functions for optimizing operations by integrating environmental impact and economic efficiency, and promote the establishment and dissemination of the foundation for a sustainable society.

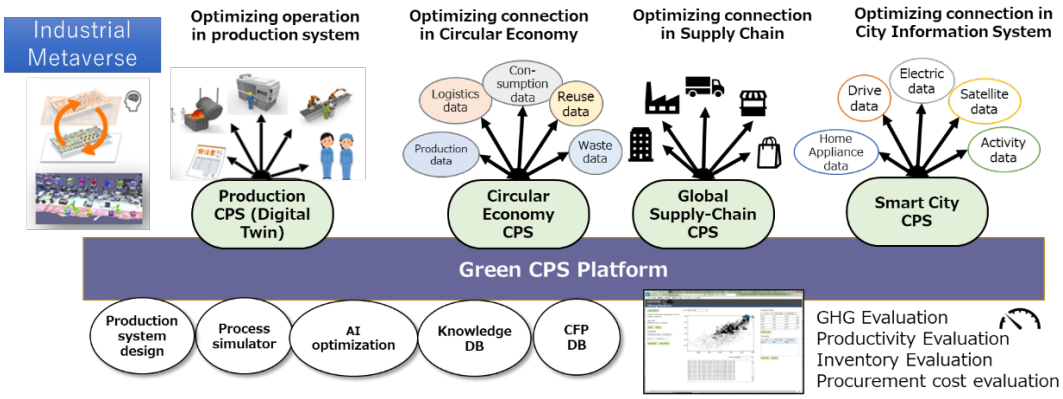


Fig. 14: CPS platform deployment

13. Purpose of establishment and activities of the Consortium

In order to realize the objectives described above, we believe that it is important to develop the activities as a multi-organizational collaboration with the fundamental technologies at the core, and have established a general incorporated association in 2022 that brings together the knowledge of industry, academia, and government. We have established a general incorporated association that brings together the knowledge of industry, academia, and government in 2022. Here, we are working together to develop new green strategies and promote them widely in society together with our stakeholders. Academic experts in the fields of carbon neutrality (CN), circular economy, and production systems, as well as participants from the manufacturing industry, telecommunications, electric power, construction, logistics, finance, consulting firms, and others, are invited to participate. The Consortium is promoted as an activity to build the future society. The following are the guidelines for the activities of the Consortium.

■ Design for carbon neutrality

We seek to clarify the steps to be taken to reduce GHG emissions in on-site reform

activities by making it possible to evaluate GHG emissions based on the design of business systems and operations.

- **To be able to correctly evaluate and reflect on-site and corporate efforts.**

  In addition to evaluating the results of activities toward CN, we will ask what measures have been taken and what efforts have been accumulated toward the results, and we will pursue the concept for this.

- **Accumulate GHG emissions, convert them into data, and promote their mutual use.**

  We aim to establish a framework that contributes to the reduction of GHG emissions by allowing each participant to accumulate GHG emissions data from Japan and overseas, as well as to aggregate, upgrade, disseminate, and mutually utilize their own knowledge.

- **Development of a CPS to promote the overall optimization of GHG emissions.**

  Promote activities to build various collaborative applications on the "Green CPS Platform" and promote the spread of support functions that integrate and optimize GHG emissions and economic efficiency.

- **Provide learning opportunities for each organization and support their level up.**

  To understand the activities of each company in the subcommittees established by the organization, and to obtain opportunities to share knowledge and learn in order to lead to further reforms in participating companies.

- **Promote environmental awareness-building education for members of the organization, students, and the public.**

  One of the goals of this activity is to foster awareness of environmental issues. For example, through the dissemination of an educational system that fosters awareness through gaming, we will promote the fostering of the ability to take action toward social issues.

To promote such activities, we have prepared a CFP calculation tool as shown in Figure 15, and are promoting activities toward carbon neutrality while member companies utilize the tool.

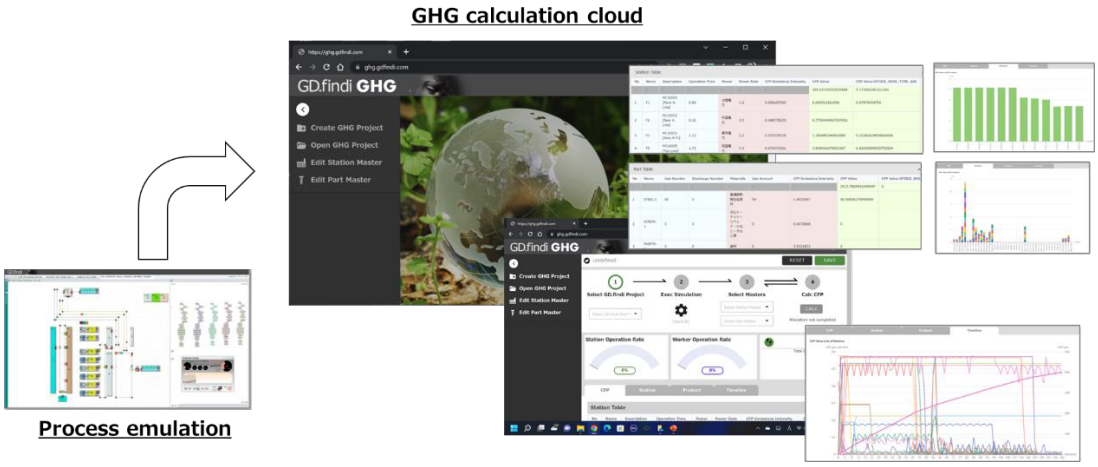


Fig.15: Process simulation and GHG calculation cloud used by the Consortium.

In this area, although the ISO, GHG Protocol, and other standards for CO2 emissions are the foundation, the guidelines will be changed successively in accordance with the demands of the world. In other words, it is important to understand new ways of thinking and to introduce new ways of dealing with the realities of society. In other words, it is necessary to comprehensively promote activities from various perspectives, such as environmental impact assessment, life cycle engineering, and circular economy, concerning carbon neutrality. For this reason, the Consortium has established a comprehensive support system by inviting Japanese leaders in these various fields to participate as board members and advisors (Figure 14). The Ministry of Economy, Trade and Industry (METI), the Ministry of the Environment (MOE), and other government policy makers also participate as observers, creating a strong collaboration between industry, government, and academia. Furthermore, since today's supply chains are not limited to Japan, but also include close relationships with other countries, especially in Asia, we are expanding our networking efforts, especially in Asia.

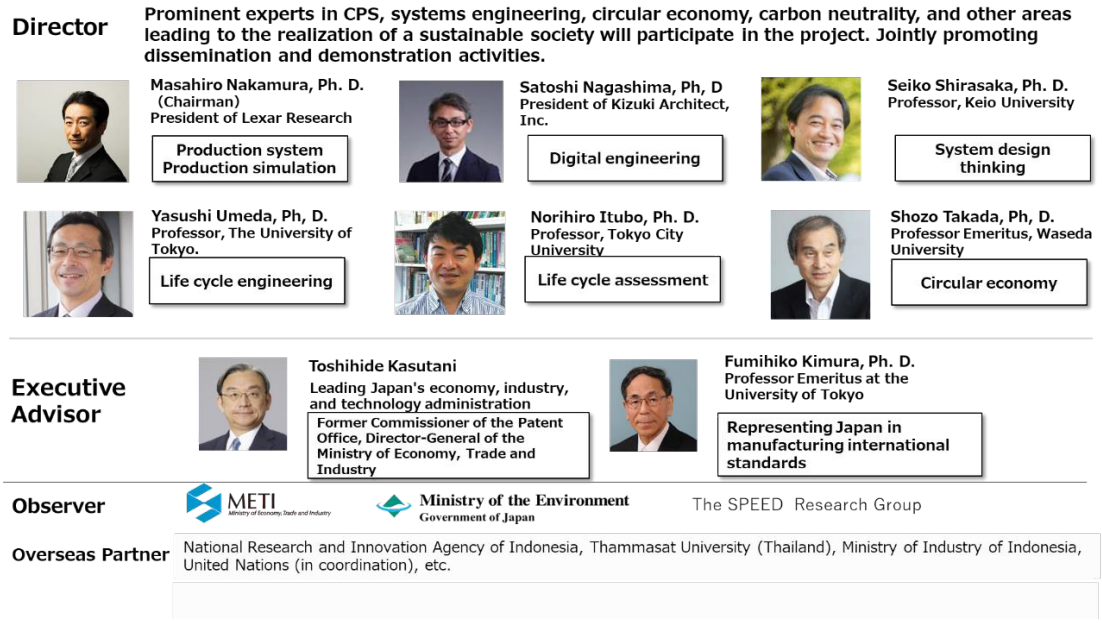


Figure 16: Participating members of the Green CPS Council

14. Model demonstration

Based on these concepts and systems, the Consortium is promoting practical social implementation. As a first step, we are promoting a model demonstration for CFP quantification with manufacturers to verify the feasibility of introducing a CFP quantification method and system based on the CFP quantification guidelines provided by the Ministry of Economy, Trade and Industry. Figure 17 shows a demonstration of CFP calculation based on the suppliers' responses in the automotive manufacturing supply chain. The CFP calculation is conducted for a multi-product mass-production line, and the CFP calculation values obtained from the secondary data and the primary data are compared and verified, as well as the feasibility of the calculation on the practical side.

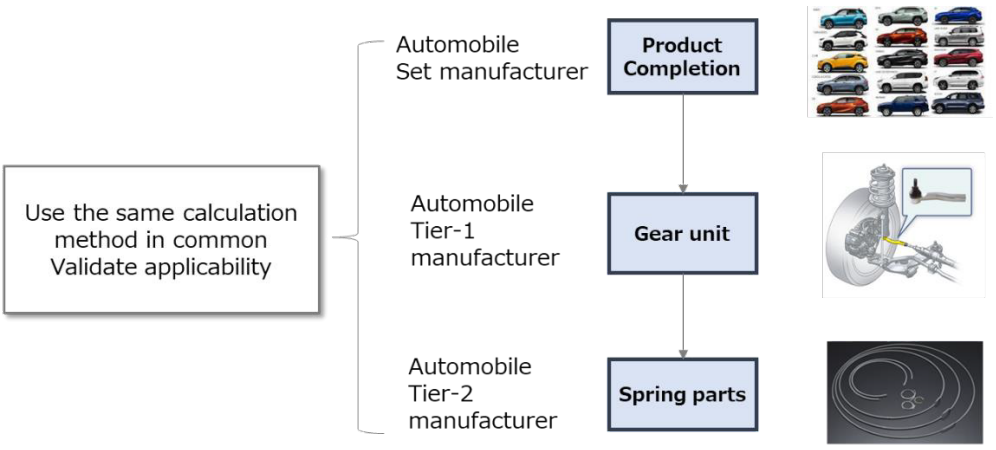


Fig. 17: Model demonstration (automotive supply chain)

In addition, Figures 18 and 19 show model demonstrations in small and medium-sized enterprises (SMEs). Here, we assume small-lot or single-part production, which is common in small and medium-sized enterprises (SMEs), and conduct the demonstration using primary data. This is important because it not only automates the calculation of product CFP, but also achieves a significant increase in productivity through digital twinning.

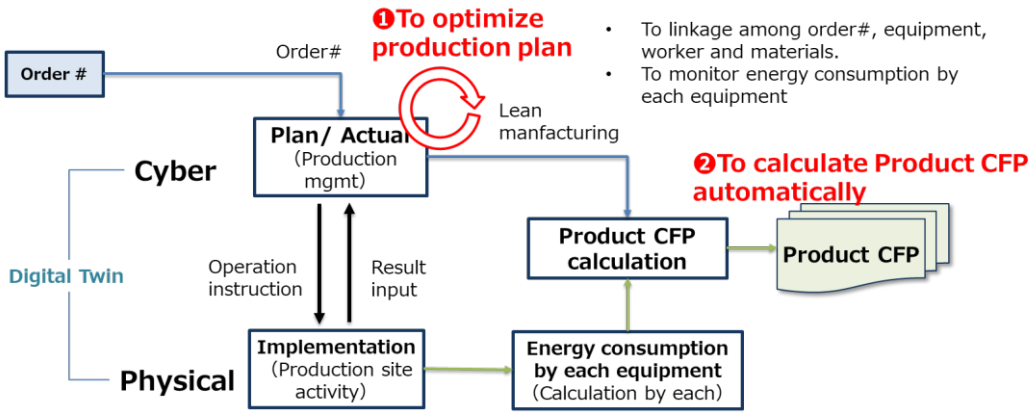


Fig. 18: Model demonstration (SMEs)

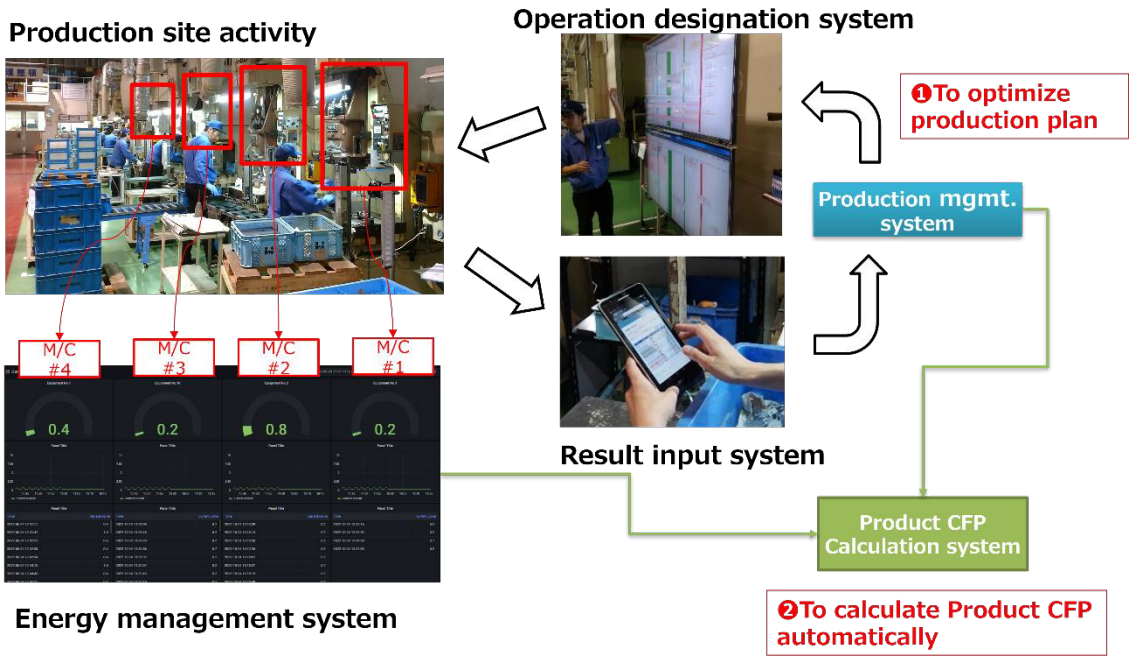


Fig. 19: Model demonstration (SMEs)

In addition to this example, we would like to promote model demonstrations widely in the future and showcase the system to serve as a practical lighthouse for many people.

15. Conclusion

The activities of the Consortium are intended to promote activities that cannot be realized by individual organizations alone, with the cooperation and collaboration of many people. We believe that it is important to take an approach that integrates not only environmental issues but also management innovation perspectives, and we look forward to the participation of many researchers, companies, and public organizations that are interested in and support the activities of the Consortium.

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