Accounting and Modeling as Design Metaphors for CEMIS

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Abstract The terms accounting and modeling both characterize the theoretical background of core components of corporate environmental management information systems (CEMIS). On the one hand, a CEMIS as a computer-based environmental management accounting system; on the other, we emphasize the role of modeling and calculation. With regard to an analysis of materials and energy flows and stocks of organizations and supply chains, accounting and modeling seem to be synonyms. However, in a software development perspective, accounting and modeling can be interpreted as different design metaphors. The aim of this contribution is to design images for computer-based CEMIS in the two perspectives. As a result, an CEMIS should be both a software tool supporting modeling activities and an information system supporting decision making.

1 Introduction

The development and implementation of corporate environmental management systems (CEMIS) is an outcome of basic research in different scientific communities. Often, the paradigms of these communities are not mentioned. The discussion of underlying images and orientations may help to improve the design process. In this contribution the different approaches of the environmental management accounting network (EMAN) and the environmental informatics community are reviewed, in particular the two perspectives “accounting” and “modeling”. The aim is to design and development images, which guideline the software implementation of appropriate software solutions.

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The implementation of CEMIS software is a challenge because CEMIS not only a next step in implementing already successful conventional accounting systems like financial accounting and cost accounting. It is not a simple extension of new data fields, evaluation procedures and reports. It seems to be necessary to discuss this special background first. As a result, a CEMIS cannot be implemented as a extension or an replacement of core components of enterprise resource planning systems (ERP systems) only. Rather, a CEMIS has to serve as an office tool (like Microsoft Excel) and as information system component at the same time.

2 Background

This section discusses the upcoming transformation of our industrial metabolism. Industrial metabolism characterizes the physical basis of our economy and society [1]. In 2011 the WBGU (German Advisory Council on Global Change) presented a report about present and future challenges, mainly in industrialized countries [2]. The title of the report "World in Transition—A Social Contract for Sustainability" expresses the most important message of the report: A socio-economic transformation is required. This recommendation is based on the insight that our industrial metabolism is not sustainable. But the consequence is not to change some physical processes (recycling processes, re-use of used materials, introduction of digital products, cleaner production etc.). We have to change our images and orientations how to organize value creation. This is not a technical problem; it is rather a question of the enhancements of our societal institutions. So, not only the industrial metabolism itself is problematic (unsustainable), highly questionable are our images how value creation should take place, the societal orientations and the societal institutions, we have established [3]. The term "transformation" describes the dynamics of future developments: It should be rather a revolution and not a relatively slow evolution.

This is not only a philosophical debate. It has relevant impacts on the successful design of CEMIS. For example, it helps to understand the success of software tools for life cycle assessment and material flow analysis. The hypothesis here is that the success of the software tools is time-dependent: they are useful in the beginning of the transition phase. Later, in a to a large extent sustainable society and economy they will be replaced by powerful ERP system components.

The question is, how we distinguish between transformation phases and the "normal" evolution of our societies. The hypothesis here is that the development and transformation of societal institutions and societal subsystems is based on communication processes of involved stakeholders, whereas in the other phase routinization replaces more and more other types of action coordination (process of rationalization). In a transition phase, stakeholders put unsustainable structures and processes in question, for instance the future of a company with regard to the scarcity of resources, consumption of fossil energy or unacceptable high carbon dioxide emissions. Here come, as one of the most important outcomes of Habermas' theory of communicative action [4], communication and discourse into play: Effective communication in such a situation aims at replacing archaic structures, mechanisms or orientations by new mechanisms and orientations, which are the essence of the communication processes: a new social consensus or contract. In this perspective, the term transformation stands for a communication process.

The consequences for the development of CEMIS are significant. Figure 1 shows the degree of formalization and routinization of organizations, institutions and societal subsystems in time. Normally, the aim of scientific disciplines like business informatics is to contribute to an increase of formalization. However, the discussion about the upcoming socio-economic transformation points out that this is not always helpful. Benefits of CEMIS are different and time-dependent. A CEMIS should integrate at least three different perspectives:

1. Before a transformation phase CEMIS should support the challenges of archaic structures, mechanisms and orientations. They should initiate communication and discourse. With regard to sustainable development, a CEMIS should help the stakeholders to identify challenges of non-sustainability.
2. In the transformation phase CEMIS should contribute to effective communication. They should help to find new (and more sustainable) mechanisms and orientations. In other words, CEMIS should provide an environment for organizational communication and learning and as a result good arguments.
3. Step by step the CEMIS has to support the new consensus by providing new mechanisms, work flows, accounting systems etc.

This makes clear that a CEMIS is not only a software implementation of new accounting systems, in particular environmental management accounting systems. Rather, the accounting system as a design metaphor may help to integrate the three requirements on CEMIS. In the following the basic ideas of accounting systems are presented.

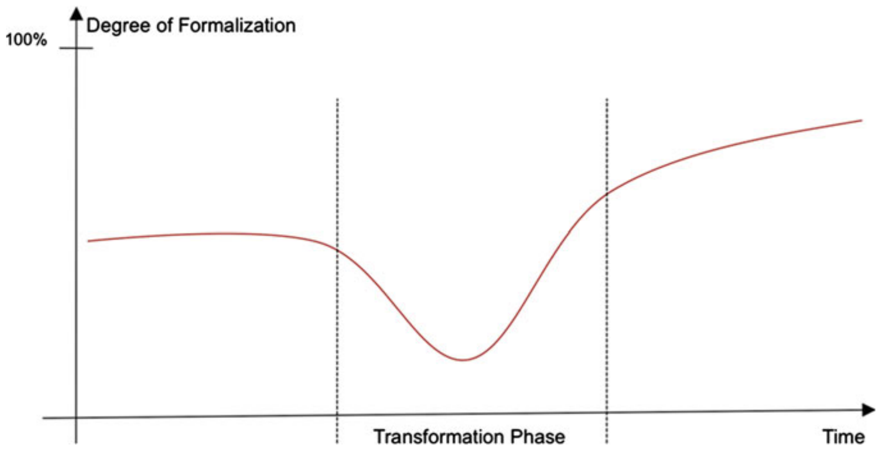

Fig. 1 Degree of formalization and the challenge of transformation phases

3 Environmental Management Accounting

Environmental management accounting (EMA), [5, 6] can be defined as a domain of new accounting concepts in addition to conventional accounting approaches like financial accounting and cost accounting [7]: environmental accounting. The accounting systems have to prepare information for different stakeholders. In case of financial accounting the stakeholders are external parties, in case of cost accounting the management. Cost accounting is a subclass of management accounting systems.

Material flow networks (MFNs) and the underlying Petri nets can be interpreted as mathematical foundations of an environmental accounting system, which allows representing material and energy flows and stocks for a specific time period [8, 9]. The static structure of Petri nets enables specifying a chart of accounts (stocks and flows). Even if Petri nets are developed for a different application domain, the static structure both of Petri nets and accounting systems are very similar. We can apply the logic of double-entry bookkeeping the Petri nets: Double-entry bookkeeping provides information on what financial flows have occurred in a period under review and how the opening inventory has changed after this period. But with regard to environmental accounting, instead of financial flows energy and material flows and stocks are considered. Stocks are assigned to the places and flows to the arcs.

The aim of environmental management accounting as a management accounting approach is to support management planning, control and decision-making [10]. Computer-based information systems provide required information (with regard to environmental management [11]). Even if the application of accounting systems to strategic management is claimed very often, the really successful application domain of accounting systems is still operations management.

However, a CEMIS, which implements accounting approaches only, cannot cover all requirements on CEMIS software mentioned above. The main focus is on the third perspective: EMA should contribute to ensure rationality in management processes [12]. In other words, CEMIS should support eco-controlling. In this perspective, there is a gap between orientations of managers (sustainable company) and appropriate decisions on the one side and on the other side the reality of the industrial metabolism and the role of the company within the industrial metabolism. Instruments like life cycle assessment [13] and product carbon footprinting try to quantify the position and role of the company. Therefore, it is required to include external data about the impact of pre and post chains, the impacts in the use phase and end-of-life impacts (waste disposal and recycling).

But what are the key characteristics of an accounting system as a decision support instrument? In this regard, it should be possible to provide data in different dimensions [9]. For instance double-entry bookkeeping as an approach of financial accounting supports the enterprise balance as well as the profit and loss statement. So, this concept provides information about “stocks” (enterprise balance) and “flows” (profit and loss statement) at the same time.

An environmental management accounting system has to cover different purposes too. With the industrial metabolism in mind, an accounting system should not only present flow data. Stocks are the main problem: the amount of available resources, the scarcity of fossil energy, the concentration of carbon dioxide in the atmosphere etc. So, if we want to draw a picture about future states of the industrial metabolism, we will need a balance (like an enterprise balance) and instruments, which are equivalent to the profit and loss statement: Stocks and the management of the stocks (flows) characterize the state of the industrial metabolism.

Data collection and data entry of the (environmental) management accounting systems seem to be an internal problem of the instruments. Nevertheless, efficient data collection and data processing become major research fields of business informatics. Several approaches are discussed and implemented, for instance the re-use of already existing data sets within ERP systems, an enhanced monitoring of formalized workflows etc.

With regard to EMA systems, this makes sense as part of eco-controlling, in particular to control decisions: The accounting systems provide data, which allow analyzing the gap between expected impacts of decisions and the real outcomes. Here, the accounting system is mainly past-oriented. This makes it possible to collect data by monitoring real business processes. Such a solution is not possible in future-oriented accounting systems [14].

4 Modeling as Indirect Data Collection

Of course, an established cost accounting system is a model. The model represents past or future states and processes of an organization. Methods are applied to derive key performance indicators from the model. A typical example is double-entry bookkeeping. As mentioned above, double-entry bookkeeping results in a consistent model, from which the enterprise balance and profit and loss statements can be derived. The methods behind allow the aggregation of data in a consistent way.

The originally intended way of data collection was "paper-based" with aid of journals and paper-based accounts. Today, computer-based corporate information systems support financial accounting, and the journal is computer-based. The software systems help to collect data sets as efficient as possible and to use them in different ways: as data input of financial accounting, as data input of cost accounting, in invoice processing etc. The idea is that we can derive the data input of the accounting systems from routinized and formalized business work flows.

But such a way of data collection is not applicable in future-oriented accounting systems. In future-oriented accounting systems, manual data collection must be replaced by (more or less sophisticated) simulation models, which draw a picture of future processes and states. These simulation models represent future scenarios, and it is possible to experiment with the models by changing the scenario parameters: assumptions about the development of prices of raw materials and intermediate goods, the market demand, the regulatory framework etc. [15].

A typical example for such a modeling system is process flowsheeting in chemical industry [16]. Process flowsheeting is used to design chemical processes, which consists of several different unit processes like mixers, chemical reactors, flash units etc. The chemical processes are embedded into complex productions networks for chemical substances and products, a so-called “Verbund”. Process simulation software determines “the size of equipment in a chemical plant, the amount of energy needed, the overall yield, and the magnitude of the waste streams” [17] by calculating dynamics and in particular steady states of future processes. The financial and ecological impacts can be derived from the models: The process model serves as a data provider of future-oriented cost accounting and life cycle assessment.

As a consequence, a CEMIS, which wants to cover future-oriented environmental accounting, cannot be an enhancement of computer-based accounting systems for financial and management accounting without a modeling component. The first prototype of a software tool, which was based on the material flow network approach, was an accounting system only. Of course, it was passible to calculate eco-balances, but so-called transition specifications were not provided. Such an accounting instrument was useless because of an exorbitant effort for data entry. It is necessary to provide a modeling component, which includes an appropriate user interface [30]. The insights from the first MFN prototype and an analysis of existing material flow analysis and life cycle assessment tools clarify that this is helpful in case of past-oriented environmental management accounting too [18]. The life cycle models include all attached pre and post chains so that the whole product life cycle serves as data input of life cycle impact assessments.

As another consequence, the application domain of future-oriented accounting systems is quite different. Application software in this field can be characterized rather as a “tool” [19]: quick what-if-analyses, experiments, rapid enhancements of the model, by the way model validations. The laptop serves as a workbench for environmental modeling and simulation.

The introduction of a modeling component and an appropriate user interface has remarkable side effects. Data collection is not longer invisible and formalized data processing, which takes place within a software system. Stakeholders are involved, and they interact with the software system to construct and to configure the models. This is not only a special kind of data entry; it is a learning process too. Not only the key performance indicators of the models provide new insights, the modeling process itself does: We better understand the physical processes, the relationship between product output, waste and emissions; we identify possible improvements and analyze them in a special scenario; we learn to interpret the numbers, for example the results of life cycle inventories and impact assessments. The modeling experiences could be the trigger of communication and improvement processes, resulting tables and figures may serve as good arguments, for instance as part of Powerpoint slides.

5 Design Images and Design Metaphors

From a management perspective, CEMIS are management accounting systems and therefore decision support systems. This image in mind, main focus is on “key performance indicators” (KPIs). Data processing within the accounting system takes place on the basis of an underlying accounting approach. In case of environmental management accounting the material flow networks may serve as such an accounting approach. “Accounting” can be interpreted as a design metaphor for a respective software component.

As mentioned, data collection is not a key issue of an accounting system. Here, already established computer-based information systems come into play. To use available data of these systems, a CEMIS component should serve as a data mapper to the respective information system. Here, conventional design metaphors like the “integrated system” [20] can be applied.

However, such a data mapper is not sufficient to cover all requirements on EMA data collection. Typical process specifications in the EcoInvent database for life cycle assessment [21] make clear that each process step has several physical inputs and outputs, which have no market price. Other computer-based information systems like ERP systems do not provide data about these flows.

A CEMIS should provide another software component: a modeling component. The modeling component contributes to close the data gaps by providing (small) models, which allow calculating unknown material and energy flows, e.g. the amount of emissions in a combustion process based on the Diesel input. The modeling tool plays the role of a customizing tool, which links available data of the information systems with databases like EcoInvent.

Moreover, the component is the “workbench” for future-oriented modeling material and energy flow models. The term “tool” may serve as a design metaphor for the component. Figure 2 shows the resulting core components [22, 23] of a CEMIS, which separates accounting from modeling as part of data collection. The framework consists of two important pillars: (1) data entry for past-oriented environmental accounting, and (2) modeling for future-oriented environmental accounting.

5.1 CEMIS as an ERP System Component

The first pillar “(1) Data Mapper ERP System” result in a CEMIS design image, which focuses on an integration into already existing computer-based information systems, mainly ERP systems. In this regard, the CEMIS becomes a decision support system. It serves as a management instrument for eco-controlling. The ideal is a fully integrated information system: the CEMIS should be integral part of ERP systems, no problems with data transfer, no problematic redundancy of data etc. A first step in this direction could be a new CEMIS component as an add-on of

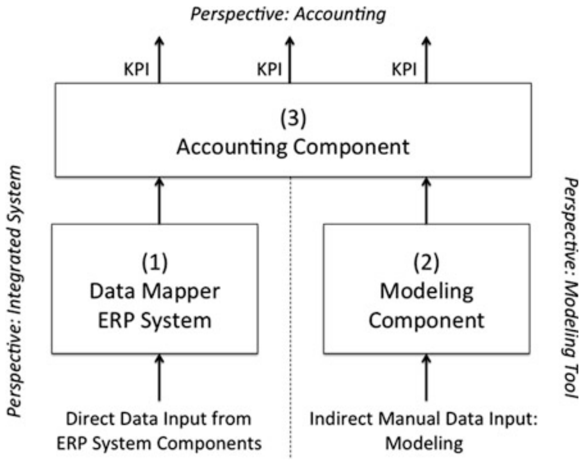

Fig. 2 Core Components of a corporate environmental management information system

already existing ERP systems. The CEMIS becomes an "observer" of all relevant data processing within the ERP system and extracts relevant data. The design images and metaphors of this pillar are in line with expectations, what such an information system should do [24]. Of course, such a component cannot be a stand-alone tool on a laptop or PC.

5.2 CEMIS as a Modeling Tool

The second pillar "(2) Modeling Component" results in a completely different design image. The CEMIS is at first a modeling tool with an appropriate user interface.

The tool helps to model flow sheets or networks of interrelated transformation processes. Users handle with processes, arrows and other graphical elements as the "material" in the design process; they "draw" with aid of the software tool processes and stocks, they link the processes (direct manipulation, [30]); they test the already designed parts of the model etc.

The users do not enter flow and stock data directly. Rather, they regard the processes as sub-models. So, the modeling process is mainly a specification processes. Sometimes fairly sophisticated modeling methods take place, for instance thermodynamic models in chemical industry. The purpose of calculation engines is to compile a consistent material and energy flow model, which integrates all specifications ("the sequential modular approach to flowsheeting" [16]).

The resulting materials and energy flow models serve as data input of appropriate accounting systems. The link to accounting systems can be realized in two different ways. (1) Data mappers transfer the results to data input of the accounting system. This could be a successful approach for already existing simulation models. (2) A second approach integrates the accounting system in a way that the calculated material and energy flows can be used directly as data sets within the accounting component. This requires that the modeling tools adopt the structures, specified in the accounting system, as a flow sheet or network structure of the modeling tool. The software tool Umberto is an example of the second approach.

The second approach avoids data gaps and mapping problems between the modeling tool and the accounting system. Moreover, the integration of modeling method and accounting system approach is prerequisite of an integration of the two different pillars of CEMIS. I will discuss the question of integration in the next section.

5.3 CEMIS Integration

The two pillars of data input of environmental accounting result in different software design images and software implementations. Normally, software frameworks implement a single basic design image only. It seems that we have to decide: the "software tool" or the "integrated system". My hypothesis is that it is possible to integrate these different images: An integrated CEMIS as a software framework [25] should consist of both a local PC-based modeling component and a server-based ERP system component. The accounting system serves as an integration component.

As discussed above, it is recommended that the accounting component provides the static structure of the material and energy flow models. In a stand-alone tool, the two different construction activities are integrated: the design auf the accounts and the relationship between them on the one hand and the specification of processes as sub-models, of feed streams and of scenario parameters on the other hand. But this is not necessarily the case. The accounting system may serve as a template for the specification processes: We "import" the network structure as the structure of the present real scenario [26], specify the processes and may be modify the structure (in a systematic way). As a result, we can calculate a future scenario. The same specifications may serve as a set of material and energy flow and stock accounts, which, as a real scenario, can be filled with data with aid of an ERP system component. The following figure shows a simplified entity-relationship diagram, which shows that it is relatively easy to separate the entities, which are required to represent the specific accounting system, from other entities, which are scenario-specific. This includes not only stock and flow accounts but also process specifications.

Modern technologies like web services and synchronization mechanisms make it possible to integrate local and remote components into a consistent software framework. The modeling components, running on personal computers, serve as a customizing tool for the real scenario and as a modeling tool, which derives future scenarios from the real scenario, provided by the ERP system. The first step of developing a future scenario is to "download" the real scenario from the ERP system (Fig. 3).

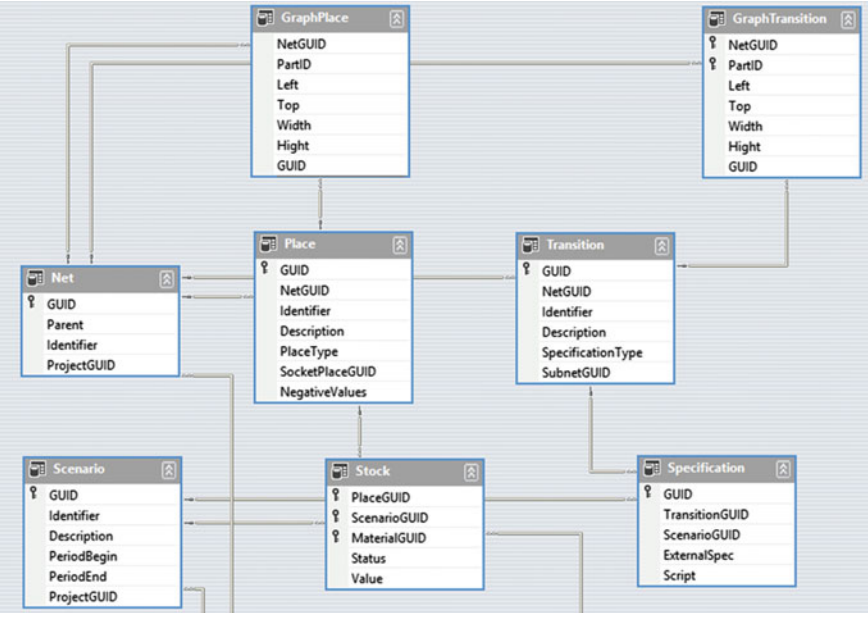

Fig. 3 Entity-relationship diagram (simplified) of an MFN-based CEMIS with three scopes: graphical user interface (GraphPlace, GraphTransition), accounting system (Net, Place, Transition) and scenario-related entities (Scenario, Stock, Specification)

6 Conclusions

This contribution discusses several arguments to develop a CEMIS as a software framework that relies on two different pillars: an ERP system component for past-oriented environmental management accounting ("accounting") and a PC-based modeling component, which allows design future scenarios ("modeling"). The consistent integration of future- and past-oriented data facilitates efficient eco-controlling. The PC-based modeling component can be designed as handy and easy-to-use office software. We use such an "App" as we use Excel and Power-point: in office, at home, on a business trip etc.

Decision support is not the only outcome of such a framework. Important are the side effects of using powerful modeling and simulation tools. We can develop and compare different scenarios; we can experiment with the models; we can assess the effects of specific improvements; we can compare different alternatives etc. Moreover, it is possible to find out problematic and unsustainable processes and structures; it is possible visualize possible improvements and differences between the real scenario and possible improvements, for instance with aid of Sankey diagrams [27]. In other words, the modeling component serves as a trigger of improvement processes, which question archaic structures and mechanisms. But as mentioned above, the modeling component does not only trigger improvements on the level of physical flows and stocks. It contributes to necessary communication processes [28, 29] which play a central role the transformation process towards a sustainable economy and society.

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