# A Study on Analysis Support System of Energy and Environmental System for Sustainable Development Based on MFM and GIS

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**Abstract.** An analysis support system has been developed of various energy and environmental system for the sustainable development. The proposed support system can model, and simulate the flows of matter, energy and information with tens or hundreds of elementary processes in the target energy and environmental system. It is based on the combination of Multilevel Flow Model (MFM) and Geographic Information System (GIS) and it can account various indices for sustainability. The values of the evaluation indices can be utilized to not only test the feasibility of one scenario but also carry out the inter-comparison of various optional scenarios. As a case study, introduction of hydrogen production system in a local town is investigated by the proposed analysis support system.

**Keywords:** MFM, GIS, Analysis Support System, Sustainability Development, Energy and Environmental System Evaluation.

## 1 Introduction

The sustainability of the energy and environment is a vital issue for the survival of entire humankind. Achieving sustainable development of energy and environment on a large scales from the world, a country, even to a local town requires the judicious use of various energy technologies[1]. In order to plan the suitable usage of energy technologies and to monitor the environmental consequences caused by energy technologies, an analysis support system is proposed in our study based on MFM and GIS. The MFM is a kind of semantic graphic modeling method not only to describe the hierarchical structure of objects from goal to function and to component, but also to represent the ''internal process'' of physical behavior by flow structure of mass, energy and information by using a series of standard symbols[3]. Traditionally, the MFM has been mainly applied in the process control areas ranging from signal validation, fault monitoring, fault diagnosis to procedure generation and human modeling, etc[4] [5][6] [7]. While in our study, the applications of MFM are extended to analyze and evaluate various energy and environmental systems from the aspects of sustainable development.

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Various energy and environmental systems have the same morphological character as that of the process plants because they have the flow networks of matter, energy and information in the process system, although the issues and application methods are rather different from the process plant. In this respect, one feature of energy and environmental system is the usage of geographical information. It should be also introduced in the study of energy and environmental systems.

The GIS is a computerized system designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information which affect the energy and environment problems(especially various renewable energies) [10][11][12][13][14].

The combination of MFM and GIS can provide a comprehensive and easy-understanding interface to carry out the analysis and evaluation of energy and environmental system from many aspects of sustainable development.

## 2 Basic Issues for Evaluation of Sustainable Development

### 2.1 The Sustainability Energy and Environmental System

These days, "sustainable development" has become a popular keyword for the future of human civilization or national/international developments. It has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. A set of evaluation indicators called Energy Indicators (EI) have been proposed by IAEA for evaluating sustainable development at a national policy level from the three aspects of social, economical and environmental factors[1]. Although IAEA's EIs are rather national level, it is always necessary to set and think in mind such kinds of Evaluation Indicators (EIs) for the evaluation of energy and environmental systems of any level. The sustainable energy and environmental system such as metropolitan waste recycle system, natural gas delivery system, HTGR(High Temperature Gas Reactor) cogeneration system even the hydrogen economy society in future, are all hierarchical and complicated network system which is constituted of the various processes such as generation, conversion, transportation, distribution and consumption of various matters and energy in various forms. And there exist various interactions between the individual elemental processes. Those interactions are considered as constraints to the individual processes. The MFM seems to be an effective tool to represent the various processes and the constraints between them [8][9] .

### 2.2 Aspects of Analysis and Evaluation

Generally speaking, when we consider the nature of sustainable energy and environmental system, there are two aspects of analysis and evaluation in common. The one is the concern of the basic technical feasibility of the scenario that the individual system would intend, and the other, the inter-comparison among various alternative scenarios from many aspects such as economic, environmental, energy efficiency even the exergy efficiency.

## 3 Prototype System Development

On the basis of the above-mentioned concept, an integrated design and simulation environment called as MFM&GIS Studio has been under development for the total analysis and evaluation of various energy and environmental systems.

### 3.1 Multilevel Flow Model -MFM

The basic functions, relationships and the connection rules, the computation rules based on connection are shown in Fig.1 and Table 1. In the computation rules columns, the “Fin”, ”Fout” and “Fs” mean the values of the matter or energy inflow, outflow and storage represented by one MFM function. Basically, there are five functions: “Source”, “Sink”, “Transport”, “Storage” and “Balance” .The Balance connects more inflows and more outflows without storage, and the sum of the total inflow equals to that of total outflow.

In addition to those basic functions, the “Relation” is used to represent all the of MFM functions to realize the “Goal”. Before constructing the Goal relations, the functions are grouped into “Networks”, each of which describes a flow of matter, energy, or mixture of them. There are two relations in MFM: the “Achieve” relations between networks and goals which indicate that all functions in the network must work as designed to achieve a certain goal; the “Condition” relations between goals and functions which indicate that the function is available only after the goal is achieved.

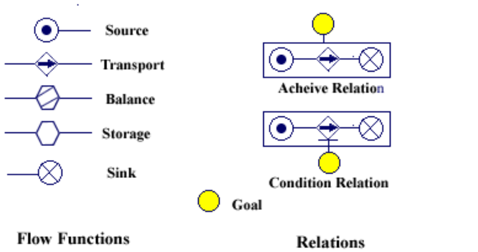


Fig. 1. The basic MFM functions and relations

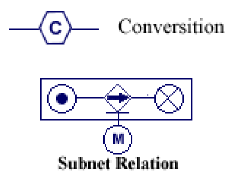


Fig. 2. New function and relation

**Table 1.** Basic connection rules and calculation relation

| Type | Connection (Input/Output) | Computation rules |
|---|---|---|
| Source | Transport(0/1) | Fin=0,Fs=0 |
| Sink | Transport(1/0) | Fout=0,Fs=0 |
| Transport | Source, Balance, Storage and Sink(1/1) | Fin=Fout, Fs=0 |
| Storage | Transport(1/1) | $\Delta$Fs=Fin-Fout |
| Balance | Transport (Multi/Multi) | $\Sigma$ Fin= $\Sigma$ Fout, Fs=0 |
| Conversion | Transport (Multi/Multi) | $\Sigma$ Fin= $\Sigma$ Fout, Fs=0 |

By the definition of the authors' study, in order to express the matter flows and energy flows clearly, all the basic function of MFM only can be used to express one kind of matter or energy. However, when the conversions like chemical reactions happen, even though the total mass and energy are conservation before and after the reaction, the types of matter or the energy may change. So a new function called "Conversion" is introduced to express this situation as shown in Fig.2. The function-"Conversion" may have many inflows and many outflows of matter and energy at the same time while the total mass and energy are kept unchanged after the conversion process.

There is another problem in principle: that is the problem of where the boundary is. For the example of the MFM describing the hydrogen production from electrolysis of water, we can define the electricity is the boundary when you do not care about where the electricity comes from. But you want to know where the electricity comes from (the solar, the wind, hydro or even the conversional fossil fuels) because different power generation has different cost and environmental consequence. In this situation, the boundary of the system should be extended to the power generation.

So a new relationship "SubNet" is introduced to describe one MFM function by a sub network in detail, and carry out the account from the aspect of economic, environmental, energy even exergy. The "SubNet" function enables the users to express the flow processes in energy and environmental system by MFM in any degree of detail.

For ca. 20 years, MFM has been successfully applied for various process control issues based on reasoning algorithm [3][4][6]. However, to analyze the energy and environmental system, various types of computing would be needed on the basis of computation rules and the mathematic formula defined by users between the two or more MFM functions. As a simple example, Figs. 3 and 4 show MFM representation and the computation rules of an energy and environmental system which describes the import of LNG from overseas and distribution to local "LNG Satellite". In Fig.4, the computation rules based on the MFM connections can be understood by referring to Table.1, and the mathematic formula $y_t = f(x_{t-1})$ between the outflow of "Overseas LNG" and the inflow of the "LNG Satellite" is defined as $y_t = x_{t-1}$. In this simple example, if you take "t" as month, the import from overseas of current month equals to the consumption of the "LNG Satellite" of the previous month. (when computing from inverse direction, the "inverse function" of the formula should be used.) The result of this example is displayed in Table.2 where the initial data at "T0" is inputted, and at the first month-"T1", the value of the outflow of "Overseas LNG" and the value of the inflow of the "LNG Satellite" are inputted, the values of other flows at "T1" can be calculated by using the basic computation rules of MFM. And at the second month-"T2", the value of the outflow of the "Overseas LNG" equals to the value of the inflow of the "LNG Satellite" of "T1", and if you know the value of the inflow of the "LNG Satellite" of "T2", all of the value of other flows at "T2" can be calculated.

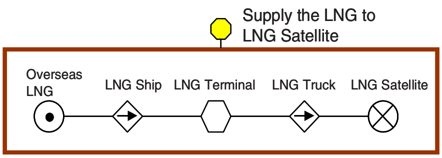


**Fig. 3.** A simple example for energy and environmental system analysis by MFM

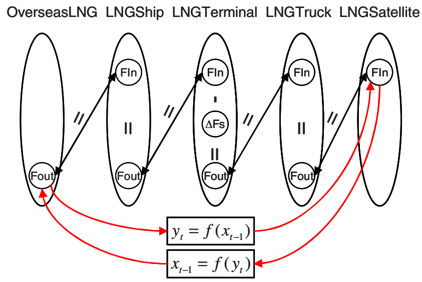


**Fig. 4.** Computation rules for the example system

**Table 2.** Computation result of the example system

| | Overseas LNG | LNG Ship | | LNG Terminal | | | LNG Truck | | LNG Satellite |
|---|---|---|---|---|---|---|---|---|---|
| | Fout | Fin | Fout | Fin | Fs | Fout | Fin | Fout | Fin |
| T0 | 0 | 0 | 0 | 0 | 0.1* | 0 | 0 | 0 | 0 |
| T1 | 10* | 10 | 10 | 10 | 0.3 | 9.8 | 9.8 | 9.8 | 9.8* |
| T2 | 9.8 | 9.8 | 9.8 | 9.8 | 0.2 | 9.9 | 9.9 | 9.9 | 9.9* |
| … | | | | | | | | | |

*: the initial data inputted by the users

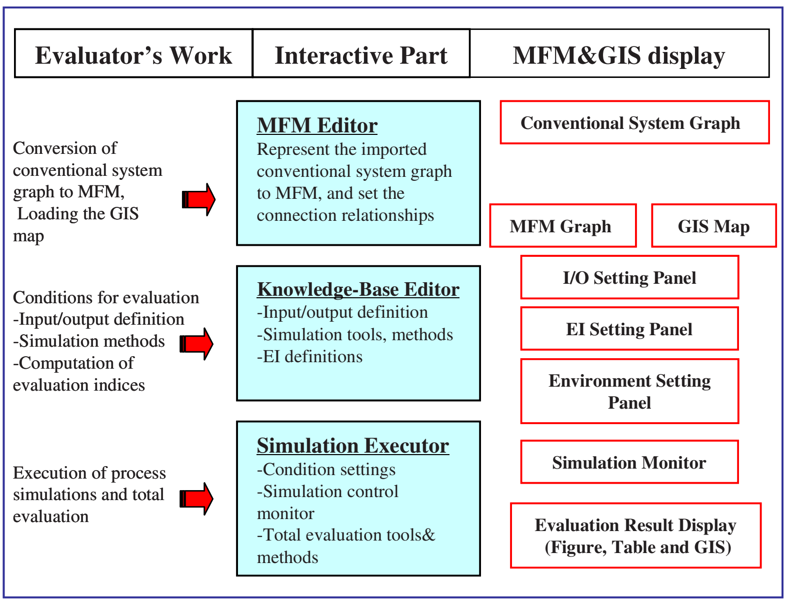


**Fig. 5.** System Design of MFM&GIS Studio

### 3.2 Geographical Information System -GIS

The GIS is a computer-based platform capable of handling spatial data that represent real world features such as urban settlements, roads, overhead lines, land type terrain, water features, wind distribution, solar intension, etc, in the form of digital maps and attributed geo-relational databases [10][11][12][13][14]. Modern GIS platforms are equipped with efficient tools able to handle enormous volumes of not only the common attribute data but also spatial data. The GIS has frequently been applied to resources and environment impact assessment, site identification as well as optimum path choice. In the developed MFM&GIS Studio, the GIS is also used to supply the necessary evaluation information and display the evaluation results visually and intuitively.

### 3.3 System Design

This system is developed by using the Microsoft Visual Studio .NET 2005 with an embeddable GIS component – MapObject2.3. And some necessary ArcGIS9.1 analysis tools (data management tool, spatial analysis tool, network analysis tool and 3D analysis tool and so on) are also used to preprocess the GIS data. As shown in Fig.5, the key components of this system are three interactive parts-"MFM Editor", "Knowledge-base Editor" and "Simulation Executor".

## 4 Evaluation Processes

Both Fig.5 and the process flow chart in Fig.6 show how these three parts work and what the user should do by the proposed support system in sequence. First, by using the "MFM Editor" the users can load conventional graph of the target energy and environmental system to be analyzed. Then the loaded conventional graph will be converted into the MFM graph based on the basic connection rules of MFM in terms of Goals-Means and Whole-Parts relationships, definition of connection relationships between the constructed MFM. In order to ensure the correctness of the constructed MFM, automatic checking will be carried out until the model become the correct ones. After that, the user defines the input/output items, the target map is loaded, and the necessary analysis is carried out to provide the spatial information for the input setting. After the I/O setting, the Flow Value (FV) computation is carried out. The "FV" not only includes the value of the inflow, outflow and storage at every MFM functions, but also includes the value of the other economic and environmental parameters such as capital cost, feedstock cost, $CO_2$ emission, etc. When the "FV" is calculated, the parameter statistics is conducted based on the FV result. The statistic can provide the total production, total cost, total $CO_2$ emission, total energy consumption, etc of the target system. After that, the users should define the other knowledge-base items such as Evaluation Indices (EI), the computing method of the EI, etc, by using the knowledge-base editor. Lastly execute the computation of EI by using the simulation executor, and the result of EI can be displayed intuitively by table or graph even on the GIS.

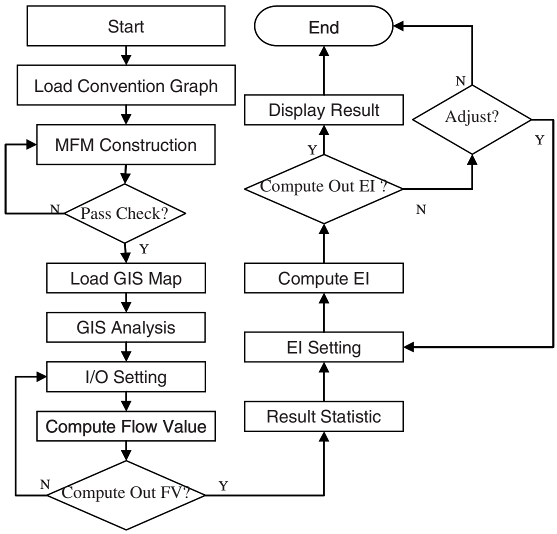


**Fig. 6.** Evaluation process of in the proposed analysis support system

## 5 Case Study

As a case study, the analysis system is applied to investigate the cost and the environmental impact of onsite water electrolysis hydrogen production system in the local city in Japan. The conventional system graph is converted into MFM representation based on the connection rules in "MFM Editor" as shown in Fig.7. The

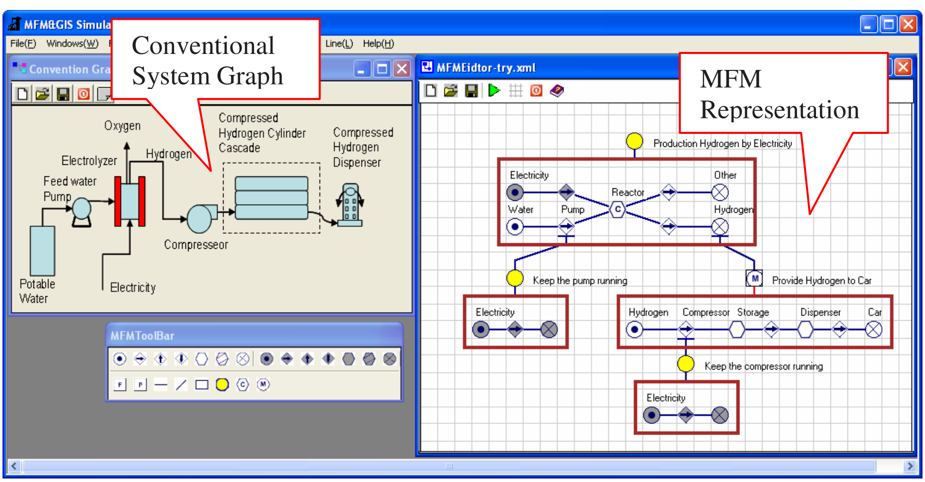


**Fig. 7.** Convert the conventional system graph to MFM in "MFM Editor"

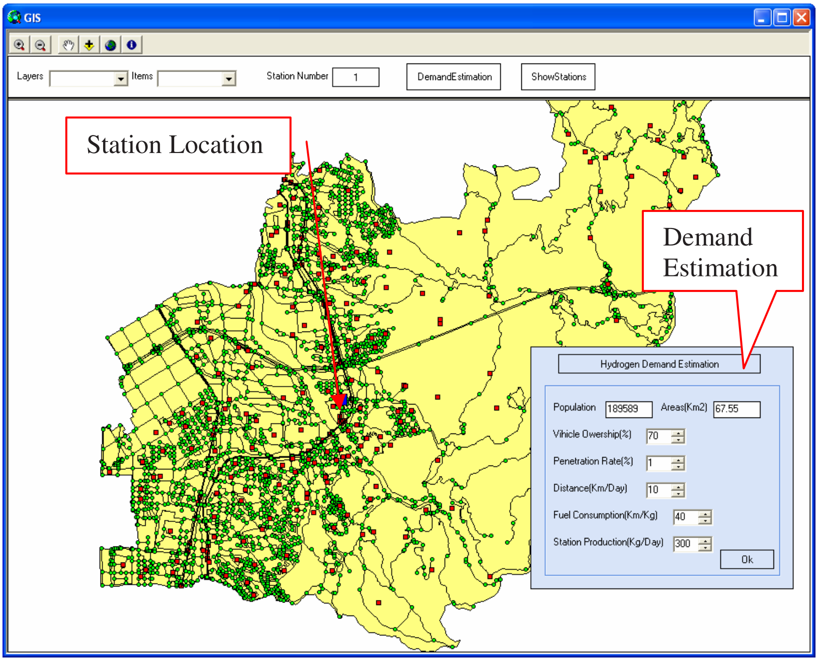


**Fig. 8.** Estimate hydrogen demand and locate optimum hydrogen station by GIS

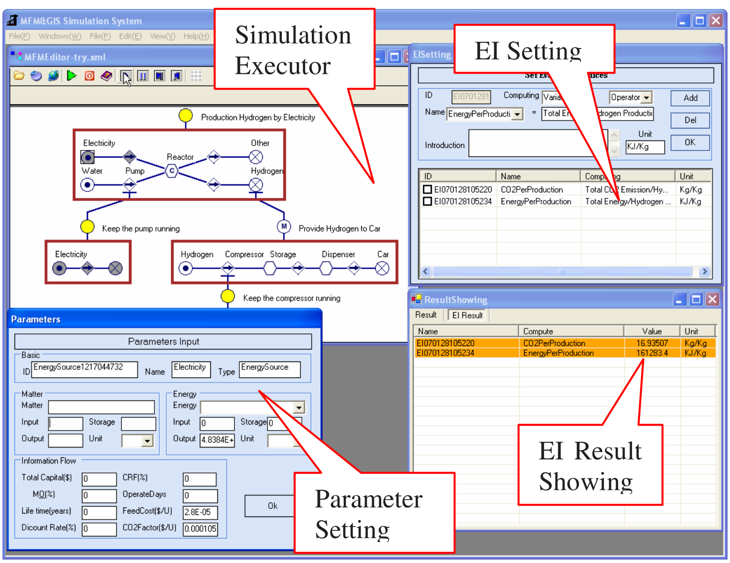


**Fig. 9.** Analysis result computation in “Simulation Executor”

GIS analysis is carried out to provide the necessary parameter values such as last demand of hydrogen and the location of the hydrogen station.[15] [16] [17] [18] As shown in the Fig.8, first, the map of Uji City, Japan is loaded to supply the necessary information such as the population, area, roads, road intersections, etc. Based on these data, the daily hydrogen demand can be predicted, and the necessary number of the stations can be estimated. Then based on the traffic flow of the roads, the optimum site of the stations can be located (the blue square in GIS component in Fig.8). Figure .9 shows the results of simulation.

## 6 Conclusions and Future Work

The concept of supporting the evaluators of versatile evaluation of various sustainable energy and environmental systems has been proposed. A new evaluation support platform MFMGIS has been developed based on the above concept, and it has been applied in some energy and environmental system. It will be further expanded for the various issues of sustainable energy and environment system such as wind energy, hydro energy, solar energy, etc based on the basic functional concepts of the target systems and necessary geographic information.

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