A Study on the Development of Evaluatuion Methods for Smart Communities

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Foreword

We are pleased to present this study report, *A Study on the Development of Evaluation Methods for Smart Communities*. This study aims to conduct a preliminary research for developing analytical methods for smart community projects in APEC economies.

Many economies are now promoting smart community to realize more efficient and lower carbon society. However, due to wide variety of smart community concepts and focused technologies, there have not been comprehensive tools for project analysis both for developed and developing economies. This study tries to sort out cost-benefit elements and develops a model with a focus on electricity system as the first step toward the development of comprehensive tools.

This report is the work of Asia Pacific Energy Research Centre. It is an independent study, and does not necessarily reflect the views or policies of the APEC Energy Working or individual member economies. However, we hope that it will serve as a useful basis for discussion and analysis of energy issues both within and among APEC member economies.

Takato OJIMI
President
Asia Pacific Energy Research Centre

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Executive Summary

Various smart community projects are ongoing in the APEC region. However, due to a wide variety of the project scope and focused technologies, there have not been comprehensive frameworks developed for project analysis and evaluation for APEC economies. Although analytical frameworks for specific projects in developed countries have been discussed in various studies, it is difficult to apply the same approach directly to the APEC region, which includes developing and emerging countries.

Against this background, this study aims to conduct a preliminary research for developing comprehensive analytical methods applicable for APEC economies. Specifically, we tried to establish a framework for cost-benefit analysis of smart community projects by sorting out cost and benefit elements (Chapter 1 to Chapter 3) and developed a power generation mix model considering demand responses, in particular electricity savings (Chapter 4). This study leads to the key findings as follows.

First, the study on framework suggests that close coordination between demand and supply side would be important at the planning and evaluation stage of smart community projects (see Chapter 2 to Chapter 3). In general, smart community projects tend to focus on efforts on demand side. However, our study shows that energy supply structure, including power generation mix, would significantly affects cost-benefit elements in demand side, and *vice versa*. The relevant planning organizations need to consider costs and benefits in the social system, as a whole, comprehensively.

Second, our model results imply that electricity savings under real time pricing would contribute to cutting peak load, although their effects are relatively modest on annual generation mix and CO_2 emissions (Chapter 4). To receive larger benefits on annual supply and demand basis, the relevant organizations need to effectively combine other pricing mechanisms, including critical peak pricing.

Third, our model results also suggest that, from the viewpoints of variable renewables integration, it would be important to appropriately combine demand-side and supply-side measures. Energy savings play a part to manage the variability, but supply side measures, including ramping operation of flexible generation, play an important role as well. Similarly to the first point above, effective combination of demand-side and supply-side perspectives need to be considered.

It should be noted that, although recent years have seen the rapid development of smart communities, the definition of the term is not clearly specified in the world. Therefore, this study defines smart community as “energy management utilizing ICT”, focusing on power consumption control.

Chapter 1 Role of Smart Communities Depending on the Status of Power Infrastructure Development in Each Country or Region

1-1 Classification of Power Infrastructure by Country or Region

In the construction of a smart community, the benefits required and the scale of their effect vary widely among regions depending on the status of power infrastructure development in the region. As the first step to discussing the cost benefits of smart communities, the status of power infrastructure development is simply classified, and the elements required of smart communities are summarized in Table 1-1 for each country or region.

Table 1-1 Status of power infrastructure development and elements required of smart communities in each country or region

Country or region	Present state of power facilities	Stage of power infrastructure development	Example of requirements for smart community
Japan	- Vertically integrated facilities - Small-scale distributed type - High automation rate - Short and infrequent power outages - Further consideration is required regarding the measures for acceptance of renewable energy.	Mature stage (Simple, advanced)	- Energy saving - Local production for local consumption - Disaster prevention - Environmental measures - Urban planning - Revitalization of regional economy - Additional value
US	- Deteriorated electric power facilities - Low automation rate - Inactive investment in infrastructure - Further consideration is required regarding the demand and supply balance and energy security. - Movement to budget infrastructure development	Mature stage (Deterioration, shortage)	- Energy saving - Temporary expedient until the completion of development of the electric power system - Commercialization as IT business
Europe	- Facilities networked with adjacent countries - Further consideration is required regarding flexible power flow control and the demand and supply balance in each country. - Electricity charges increase with the introduction of renewable energy in some countries.	Mature stage (Complicated, advanced)	- Energy saving - Local production for local consumption - Environmental measures - Promotion of the diffusion of renewable energy - Reconstruction of the social infrastructure
Emerging countries	- Active power demand - The attitude toward infrastructure development varies from region to region. - Further consideration is required regarding environmental measures such as anti-pollution measures.	Transition stage	- Development of a social infrastructure - Improved standard of living
Developing countries	- Many non-electrified regions - Overall power shortage - Further consideration is required regarding various infrastructure development.	Development stage	- Development of a social infrastructure - Improved standard of living

Source: Institute of Energy Economics, Japan

As shown in Table 1-1, the status of power infrastructure development is roughly divided into the "mature stage", "transition stage" and "development stage", and the mature stage is further divided into three categories according to the update status and power generation mix.

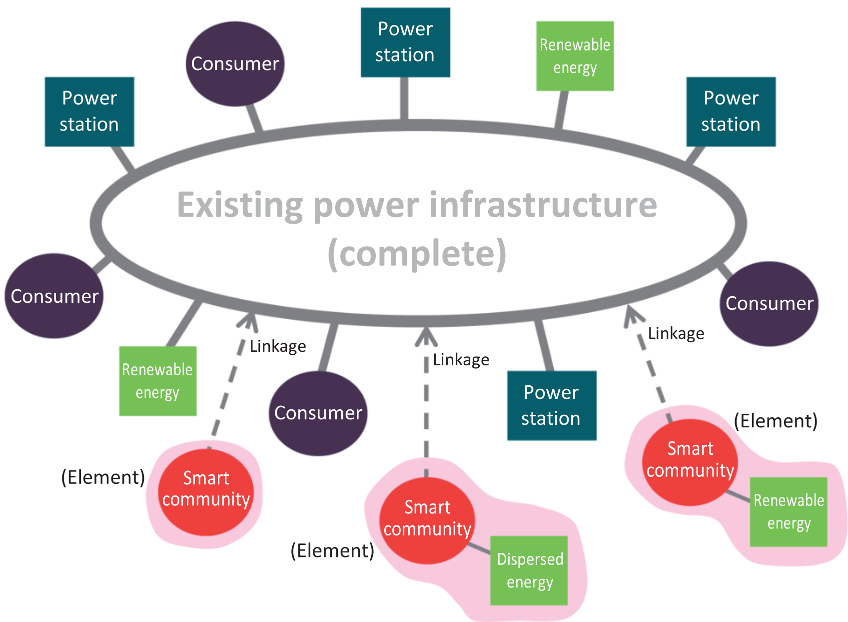
The above table also shows that almost the same elements are required of smart communities in emerging countries and developing countries suffering from power shortage, but various elements are required of smart communities in the mature stage reflecting the social background of each country or region.

1-2 Role of Smart Communities Depending on the Stage of Power Infrastructure Development

This section discusses the role of smart communities in the mature stage and the transition and development stages of a power infrastructure. In the mature stage of a power infrastructure, smart communities are considered as separate elements added to a complete power system, as shown in Figure 1-1. In other words, they are considered as added value separate from the existing power system rather than power supply added to the system in response to increasing demand.

Furthermore, being separate from the existing power system, smart communities act as an adjustment function reducing the harmful effects of weather-induced variations in power supply from renewable energy, variations in the demand and supply balance due to delay in updating the existing infrastructure, and other unstable factors on the power system, as these factors are managed in the smart communities themselves.

Figure 1-1 Power infrastructure and smart communities in the infrastructure mature stage



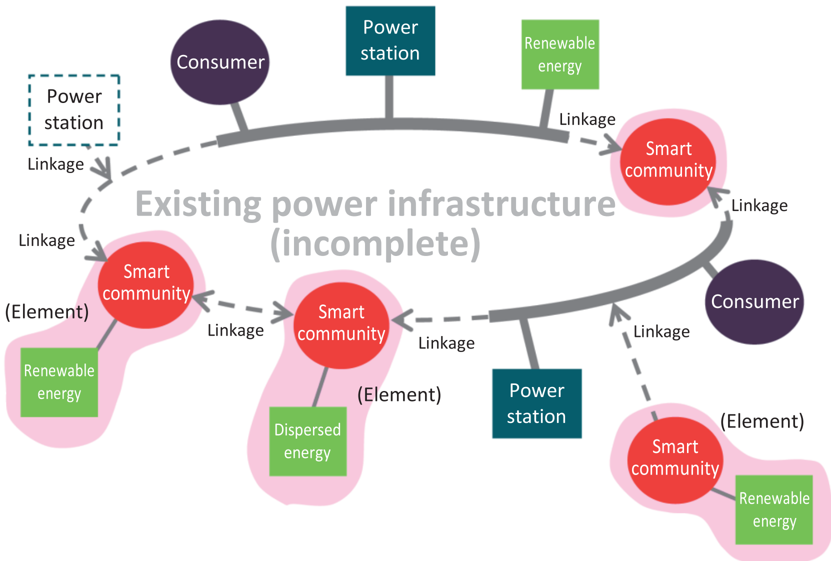
Source: Institute of Energy Economics, Japan

On the other hand, in the transition and development stages of a power infrastructure, smart communities reduce the vulnerability of energy supply for the existing incomplete power system and act as a separate, independent energy supply in areas where the power system has not yet been established, as shown in

Figure 1-2. Smart communities are linked with the power system as its development advances, and then the power infrastructure shifts to the mature stage. Thus, smart communities support the rapid development of a power system in the transition and development stages of a power infrastructure.

Smart communities also provide extra value in addition to energy supply, such as an improved standard of living and lifestyle renovation, which are more beneficial in the transition and development stages than in the mature stage of a power infrastructure.

Figure 1-2 Power infrastructure and smart communities in the infrastructure transition and development stages



Source: Institute of Energy Economics, Japan

Chapter 2 Examination of Value Evaluation Methods for Smart Communities

2-1 Value Evaluation Methods for Social Infrastructure[1]

For the value evaluation of smart communities, it is important to clarify the specific purpose of the evaluation in advance. This study assumes that smart communities are an investment in the development of a social infrastructure, and therefore evaluates the investment value of smart communities. Evaluation methods for the investment value of a social infrastructure are roughly divided into "project evaluation", "cost benefit analysis" and "risk evaluation".

The project evaluation is based on the economic effect not only at the time of investment but also from a medium- to long-term perspective. Since this method evaluates the economic efficiency, both the costs and benefits should be converted into monetary values.

Table 2-1 Project evaluation

Major classification	Medium classification	Minor classification	Description
1. Economic evaluation	(1) Cost–benefit analysis	i. Cost–benefit ratio (CBR)	Determines acceptance/rejection by the criterion of cost–benefit (B/C) ratio ≥ 1.
		ii. Net present value (NPV)	Determines whether the value exceeds the investment by "benefit − cost (B−C)".
		iii. Economic internal rate of return (EIRR)	Evaluates the rate of return on the project. Projects are considered effective if the rate of return exceeds the social discount rate (conventional value).
	(2) Cost effectiveness analysis		Compares the effect with the cost to determine the priorities and evaluate the cost effectiveness. Unlike cost–benefit analysis, this method analyzes effects that cannot be converted into monetary values.
	(3) Multicriteria analysis (Cost utility analysis: CUA)		Makes an evaluation by weighting the effect by a certain scale (utility value). The scale is sometimes selected arbitrarily.
2. Financial evaluation			

Source: Institute of Energy Economics, Japan

Unlike the project evaluation, the cost–benefit analysis does not analyze the project, but helps decide whether or not to invest in the project. Specifically, this method objectively evaluates the project by other means, such as a questionnaire, while the project evaluation directly evaluates the project.

[1] Sections 2-1 and 2-2 are based on Pacific Consultants (2002) and MLIT (2006; 2008; 2009), Otani, et al. (2012).

Table 2-2 Cost–benefit analysis

Major classification	Medium classification	Minor classification	Description
1. Noneconomic values	(1) Revealed preference methods	i. Alternative method	Makes an evaluation by alternative properties containing the effect equivalent to that of non-market properties and values.
		(a) Aversive expenditure method	Evaluates damage prevention costs and so on.
		(b) Replacement cost method	Evaluates natural environment restoration costs and so on.
		(c) Direct expenditure/revenue method	Evaluates the increase in productivity due to improved comfort and so on.
		(d) Resource value method	Makes an evaluation by converting non-market properties into economic resource values.
		ii. Travel cost method (TCM)	Calculates the monetary value of the environmental quality (such as access costs).
		iii. Hedonic pricing method	Calculates the monetary value of the environmental quality (including the living environment and comfort).
	(2) Stated preference methods	i. Conjoint analysis	Estimates the preference for each attribute of properties and services and evaluates the value of properties.
		Rating type: (a) Full-profile rating	Represents a certain profile and examines favorable impressions to make an evaluation.
		Rating type: (b) Pair-wise rating	Represents two opposing profiles and examines favorable impressions to make an evaluation.
		(c) Choice type	Represents multiple profiles and chooses the most favorable one to make an evaluation.
		ii. Contingent valuation method (CVM)	Makes an evaluation based on the results of individual surveys (questionnaires).
2. Consumer surplus			Evaluates the level that consumers feel profitable from the Marshallian demand curve and commodity prices (consumer surplus = consumer's allowable payment − commodity price).
3. National income (index)			

Source: Institute of Energy Economics, Japan

The risk evaluation evaluates the economic efficiency based on the risk and uncertainty of estimated cost and benefit elements. Specifically, this method verifies the reliability of the project evaluation results by changing unstable factors among the estimated costs and benefits and examining the influence on the effect of the project.

Table 2-3 Risk evaluation

Classification	Description
1. Sensitivity analysis for each factor	Evaluates the variation range of the value when a premise or assumption changes in addition to CBR.
2. Scenario analysis	Assumes two or three scenarios, such as superior and inferior cases, and calculates the NPV for each scenario.
3. Monte Carlo analysis	Determines the probability distribution of the effect of an uncertainty by Monte Carlo simulation.
4. Decision rule method	Determines whether to choose the best result or the minimum loss.
5. Decision tree method	Illustrates the effects of different plans on NPV in a tree.
6. Payback period method	Used as a criterion for the selection of alternative plans in a profitable period.

Source: Institute of Energy Economics, Japan

2-2 Value evaluation methods for smart communities

Since the value of a smart community is evaluated based on the investment value, it is necessary to compare the benefits brought by the smart community with the costs for the construction of the community. The following two methods are adopted considering the investigation results in Section 2-1.

(1) In cases where the investment value is determined for a certain model

This method evaluates the investment value of an assumed model from the viewpoint of the cost–benefit ratio and risk evaluation. In the evaluation based on the cost–benefit ratio, the cost–benefit ratio (CBR) is given as

$$CBR = \frac{B}{C} \quad \text{Eq. 2-1}$$

where B is the benefit and C is the cost.[2] If CBR is larger than one, i.e., the benefit is larger than the cost, the model is considered worthy of investment. In this method, all costs and benefits assumed by the model should be converted into monetary values. If the costs and benefits cannot be assumed by the accumulation method, they should be converted into monetary values, for instance, by the with-without method, which compares the total cost before and after the introduction of an event.

The risk evaluation considers the result obtained by Eq. 2-1 as a standard case and confirms the effect on CBR by giving a variation width (e.g., ±10% of the value assumed for the standard case) to each benefit or cost element that was uncertain when converted into a monetary value due to a lack of data or the like. If the CBR of the minimum variation width (−10%) is lower than the CBR expected for the model, the

[2] Davis (2012) is an example of evaluation using CBR.

model is considered not worthy of investment.

(2) In cases where the investment value is determined for multiple models

This method determines which model is the most worthy of investment among the assumed models from the viewpoint of the net present value and economic internal rate of return. In the evaluation based on the net present value, the net present value (NPV) is given as follows.

$$NPV = B - C \qquad \text{Eq. 2-2}$$

If NPV is larger than zero, i.e., the benefit is larger than the cost, the model is considered worthy of investment. In the comparison of multiple models, the model with the largest NPV is the most worthy of investment. In this method, all costs and benefits assumed by the model should be converted into monetary values as with the case of CBR. The evaluation based on the economic internal rate of return evaluates the investment limit. A model is considered worthy of investment if the following condition is satisfied:

$$\text{Internal rate of return that satisfies } NPV = 0 > \text{Social discount rate} \qquad \text{Eq. 2-3}$$

Here, NPV = 0 means that the benefit balances with the cost. Under such conditions, the rate of return on investment incorporated in the model is regarded as the internal rate of return. The social discount rate is a divisor ratio that divides future benefit and cost into a present value. In Japan, the interest of national and local debts (4%) is generally used as the social discount rate when evaluating the investment value of public works such as the construction of roads, airports and railways. Table 2-4 shows examples of social discount rates adopted in APEC member countries other than Japan.

Table 2-4 Examples of social discount rates adopted in APEC member countries

Country or region	Social discount rate
US	7% (for facilities as a whole), 4% (for water resource-related facilities)
Canada	8%
Australia	Analyzes sensitivity at 4, 7 and 10%.
New Zealand	7%
(Reference) Non-APEC countries	- EU: 6% - France: 4% - EC: 3.6%

Source: Institute of Energy Economics, Japan

(3) In cases where cost and benefit elements cannot be converted into monetary values

In the two evaluation methods described above, all costs and benefits assumed by the model should be converted into monetary values, but in reality, some are difficult to convert. In Europe and the US, where evaluation methods for public works were introduced earlier than in Japan, many countries compile even the costs and benefits that cannot be converted into monetary values and utilize them for evaluation.

Specifically, cost and benefit elements that cannot be converted into monetary values are evaluated (scored) in accordance with their importance so that even non-numerical factors can be comprehensively evaluated as quantitative or qualitative values.

With this in mind, this study compiles the cost and benefit elements of a smart community regardless of whether or not they can be converted into monetary values by creating frameworks, and develops comprehensive evaluation methods that classify the elements by whether or not they can be converted into monetary values.

Chapter 3 Creation of Evaluation Frameworks for Smart Communities

Frameworks are created for the extraction of cost and benefit elements of smart communities. Such frameworks can be created by the following two ways:

- Compile all the possible costs and benefits arising from the construction of a smart community.
- Compile the costs and benefits at each stage of introduction of a smart community in accordance with the status of power infrastructure development.

The former is a "static framework" because it is independent of any time axes. The latter is a "dynamic framework" because it is based on the time axis of stepwise introduction of a smart community.

In general, attention is paid only to the demand side of smart communities because efforts to construct smart communities are made on the demand side. However, when evaluating the investment value of a smart community, the benefits brought by the smart community also depend on the status of the power infrastructure. Therefore, this study examines frameworks considering the power generation mix. This means that these frameworks can also be used for deciding whether or not to invest in the smart community to meet the situation of each country or region. The static and dynamic frameworks for a smart community are described below.

3-1 Creation and Discussion of Static Frameworks

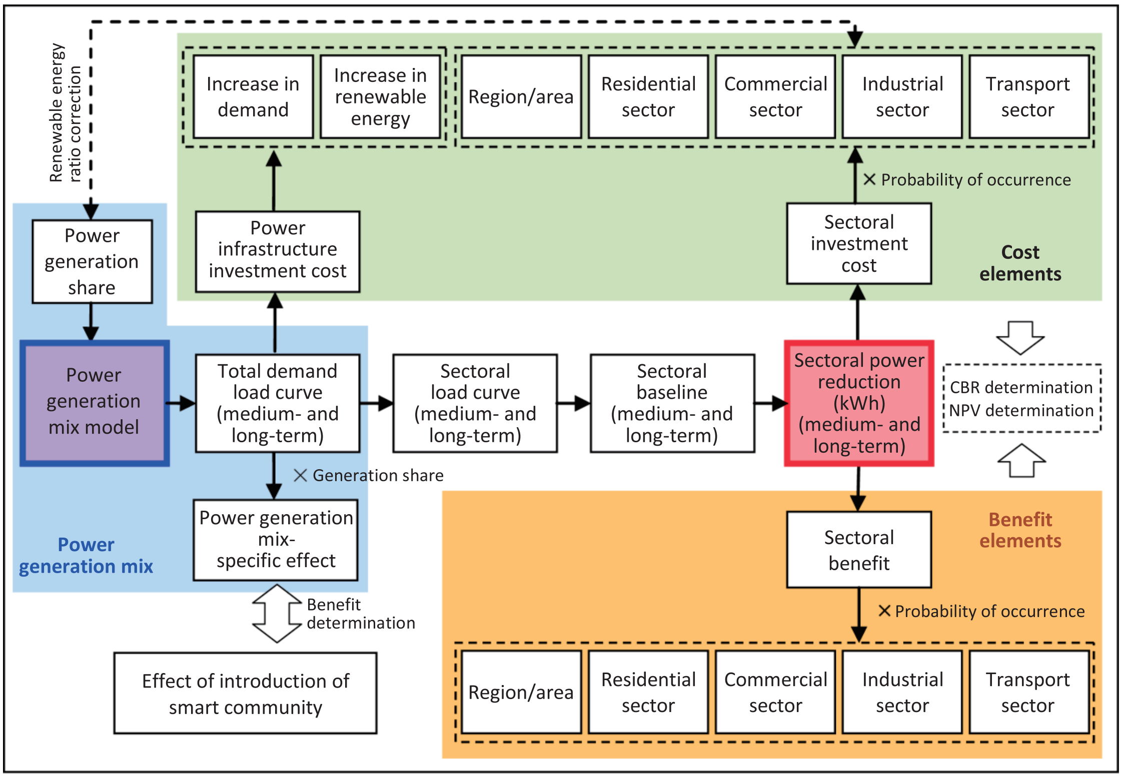
3-1-1 Extraction of Cost and Benefit Elements

A smart community is not clearly defined at present. For the purpose of evaluating the investment value of smart communities, this study considers a smart community as "energy management utilizing ICT" and extracts possible cost and benefit elements by creating frameworks focused on the amount of reduced power consumption. The extraction range does not include information business such as Internet of Things (IoT) service, which is not directly related to power saving, but includes power generation, electric power, water and other infrastructure facilities, heat source and electric equipment, and traffic facilities such as railways and vehicles.

If information business is to be considered, an enormous number of events need to be assumed because information business covers a wide range of fields. However, benefits can be estimated, for instance, for the purchase of a certain commodity by comparing the social benefits enjoyed by customers in their transportation or conveyance costs before and after the introduction of IoT.

When extracting benefit elements using a static framework, the elements should be compiled aiming for the construction of a social infrastructure with well-balanced 3E approach (energy security, economic efficiency, and environmental conservation). Figure 3-1 shows an overview of the elements compiled using a static framework.

Figure 3-1 Overview of the elements compiled using a static framework



Source: Institute of Energy Economics, Japan

When examining the cost benefit of a smart community focusing on the amount of reduced power consumption, it is necessary to obtain the amount of power demand reduced from the baseline. Load curve and consequently the amount of reduced power consumption vary from sector to sector including the residential sector, commercial sector and industrial sector. Therefore, on the demand side, the technical elements of the smart community should be extracted for each sector, and then the costs and benefits should be compiled for the extracted elements.

The power demand affects the costs and benefits of the power supply, such as CO_2 emissions and electricity charges, depending on the power generation mix. Therefore, this study also considers the relationship between the amount of reduced power consumption and the power generation mix.

After the costs and benefits are compiled as described above, those necessary for the evaluation of the investment value of a smart community are determined, and then the value of the smart community is determined by means of CBR and/or NPV, which evaluate the occurrence rate of each event and the value of smart communities.

These frameworks are used not only to extract the costs and benefits of smart communities, but also to suggest how a centralized power plant can coexist with smart communities, for instance, to find the optimum power generation mix in the presence of smart communities by evaluating the value of smart communities, determining effective technical elements, and/or changing costs and benefits in various power generation mix.

3-1-2 Cost Elements Used for Evaluating the Investment Value of Smart Communities

The cost elements that contribute to the evaluation of the investment value of smart communities are described below for each sector.

(1) Supply side: Grid (power infrastructure)

What must be determined with regard to a grid is the extent to which the power infrastructure should be developed in the future. This also depends on the status of power infrastructure development in each country or region. In addition, the demand and supply balance may need to be adjusted depending on the extent to which weather-dependent renewable energy is incorporated in the power mix. These facilities can smartly and efficiently utilize a power infrastructure in general, and therefore are collectively called a smart grid.

Table 3-1 shows the possible cost elements that could arise in the construction of a smart grid. However, costs for simple upgrading the functions of existing facilities are not included. On the other hand, infrastructure is sometimes developed not for smart communities, but to meet the suppliers' needs. Therefore, the construction of a smart grid and that of smart communities should be considered to be independent of each other in principle, but partially overlapping or related to each other. It is important to determine if smart grid related elements should be considered in the evaluation of the investment value of a smart community by examining whether or not the purpose of the smart community is consistent with that of the investment in the smart grid.

Table 3-1 Cost elements possible on the grid side

Possible cost elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Response to increasing demand			Enhancement/ construction of power system	○						△
Renewable energy system measures (ancillary measures)	Extra heating in thermal power station			○						△
	Photovoltaic power generation controller			○						△
	System battery		Lead	○						△
			Lithium ion	○						△
			Redox flow	○						△
			NAS	○						△
	Other facility measures	Power flow monitoring / voltage adjustment facility	VS with sensor	○						△
			Remote-controlled SVR	○						△
			Remote-controlled SVC	○						△
			Pole Tr with tap	○						△
Others (customer response, power information control, etc.)			Automated distribution system	○						△
			Smart meter	○						△

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , △:Case by Case

(Note) SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(2) Demand side: Region/area sector

The region/area sector means a group that contains all the sectors, including the residential sector, commercial sector and industrial sector, and makes comprehensive efforts as an area. Therefore, the costs incurred by each sector in cooperation with the area, such as the demand response (DR) service by an aggregator, are compiled for each region or area.

The possible cost elements in the region/area sector are compiled in Table 3-2. The elements to be considered with regard to the region/area sector are the status of development of private energy facilities including electric and thermal energy facilities, the state of use of demand response (DR), which is a technical element of a smart community, and efforts related to water. Efforts related to water include an element of facilities subject to power saving and also an element to be considered in strengthening a city such as disaster prevention in developed countries, and furthermore, are considered to include an important element from the viewpoint of water infrastructure development in emerging and developing countries.

In the region/area sector, there are various stakeholders for each cost. In addition to the country, economy, government and power retailers, who are the main defrayers of electric and thermal energy, developers and facility owners such as facility managers also bear the efforts related to water.

Table 3-2 Cost elements possible in the region/area sector

Possible cost elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Private power generation facility	Power accommodation	Power generation facility	Photovoltaic power generation		○	○				○
			Wind power generation		○	○				○
			Biomass power generation		○	○				○
			Geothermal power generation		○	○				○
			Others		○	○				○
		Private line				○				○
		Wheeling rate				○				○
	Heat accommodation		Conduit		○	○				○
	Ancillary measures	Battery for community (including hybrid battery)	Lead		○	○				○
			Lithium ion		○	○				○
			Redox flow		○	○				○
			NAS		○	○				○
DR service	Management system	CEMS (AMES)	Management integration system (main body)			○				○
			Linkage with management system			○				○
		Point application system				○				○
	DR incentive	No negawatt trading	Point applied			○				○
			Subsidy		○					○
		Negawatt trading available	Negawatt contract money			○				○
			Imbalance penalty charges					○		○

Table 3-2 Cost elements possible in the region/area sector (Continued)

Water treatment facility	Treatment facility	Service water treatment facility	Water purification plant		○					○
			Fresh water generation facility (desalination of seawater)		○		○	○		○
		Wastewater treatment plant			○					○
		Wastewater treatment facility	For industrial wastewater treatment					○		○
		Wastewater regeneration treatment facility	For wastewater treatment		○					○
			For industrial wastewater treatment					○		○
		Water storage facility (water level control)			○					-
	Water supply/drainage facility	Conduit	For service water		○		○	○		○
			For wastewater		○		○	○		○
			For industrial wastewater		○			○		○
		Meter	For service water		○		○			○
			For wastewater		○		○			○
			For industrial wastewater		○		○			○
		Water truck/ recovery truck	For service water		○			○		○
			For wastewater		○			○		○
			For industrial wastewater		○			○		○
	Control system		For service water		○			○		○
			For wastewater		○			○		○
			For industrial wastewater		○			○		○
			For water level control		○					-
Water DR service	Management system	Management integration system (main body)	For water saving (water cutoff) DR		○		○	○		-
			For water quantity adjustment DR		○					-
			For power saving DR		○	○	○			○
		Linkage with management system	For water saving (water cutoff) DR		○		○	○		-
			For water quantity adjustment DR		○					-
			For power saving DR		○	○	○	○		○
		Point application system	For water saving (water cutoff) DR		○		○	○		-
			For power saving DR		○	○	○			○
	DR incentive	Point applied	For water saving (water cutoff) DR					○		-
			For power saving DR			○	○	○		○
		Part of negawatt contract money	For water saving (water cutoff) DR			○				-
			For power saving DR			○	○			○

Source: Institute of Energy Economics, Japan Remarks; ○: Applicable , －: not applicable(N/A)

(Note) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(3) Demand side: Residential sector

The possible cost elements in the residential sector are compiled in Table 3-3. For the residential sector, it is necessary to consider the diffusion of smart facilities as well as that of demand response (DR) service, which is a service menu of aggregators including power retailers.

Whether smart meters owned by system operators, which are included as one of the smart facilities, are included in cost elements or not is determined depending on how the smart meters are utilized in the smart community. Specifically, smart meters should not be included in the cost elements if they are introduced by system operators for the purpose of remote meter reading. On the other hand, smart meters are included in the cost elements if they are introduced to provide additional services to consumers.

Regarding stakeholders in the residential sector, end home users and facility managers of apartment houses bear the costs for smart facilities while aggregators such as power retailers bear those for demand response (DR) services.

Table 3-3 Cost elements possible in the residential sector

Possible cost elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	System operator facility		Smart meter	○						△
	End user facility		Photovoltaic power generation					○	○	○
			Battery					○	○	○
			Heat pump					○	○	○
			Fuel cell					○	○	○
			Smart appliance						○	○
			Others (solar thermal power generation, etc.)					○	○	○
DR service	PPS/ aggregator facility	Private facility	Smart child meter			○				○
		Visualization terminal				○				○
		EMS equipment (HEMS)				○				○
		DR incentive	Calculated for the region/area sector	-	-	-	-	-	-	-

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , △:Case by Case , －: not applicable(N/A)

(Note) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(4) Demand side: Commercial sector

The possible cost elements in the commercial sector are compiled in Table 3-4. For the commercial sector, as with the case of the residential sector, it is necessary to consider the diffusion of smart facilities as well as that of demand response (DR) service, which is a service menu of aggregators including power retailers.

The difference with the case of the residential sector is the type and scale of smart facilities installed as well as the consideration of water treatment related facilities because offices such as buildings are assumed in the commercial sector. Also, since it is more important for aggregators in the commercial sector than for the residential sector to ensure the amount of reduced power consumption, negawatt trading, a service focusing on the amount of reduced power consumption, is included in the demand response (DR) service as a main element. Furthermore, commercial facilities are also included in the commercial sector. Therefore, demand response, which reduces power consumption not inside buildings but by encouraging home users to go to commercial facilities, is also included in the possible elements.

Regarding the stakeholders in the commercial sector, facility managers of buildings and commercial facilities bear all the costs.

Table 3-4 Cost elements possible in the commercial sector

Possible cost elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	Heat source facility	CGS (Cogeneration system)						○		○
			Conduit (for heat accommodation)					○		○
		Heat pump						○		○
		Others (ice storage, absorption type gas cooling, solar thermal, etc.)						○		○
	Photovoltaic power generation							○		○
	Battery (including hybrid battery)		Lead					○		○
			Lithium ion					○		○
			Redox flow					○		○
			NAS					○		○
	Management system	BEMS	Cloud type					○		○
			On-site installation type					○		○
	Smart facility		LED					○		○
			Air conditioner (including radiant heat)					○		○
			Others					○		○
	Water treatment facility	Service water treatment	Treatment facility					○		○
			Fresh water generation facility (desalination of seawater)					○		○
			Control system					○		○
		Wastewater treatment	Wastewater regeneration facility					○		○
			Control system					○		○
DR service	DR for negawatt trading	Private facility	Smart child meter					○		○
		Visualization terminal						○		○
		DR incentive	Calculated for the region/area sector	-	-	-	-	-	-	-
		Imbalance penalty charges	Calculated for the region/area sector	-	-	-	-	-	-	-
	Outing induction DR		DR system					○		○
			Coupon issuing terminal					○		○

Source: Institute of Energy Economics, Japan　　Remarks; ○:Applicable , −: not applicable(N/A)

(Note) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(5) Demand side: Industrial sector

The possible cost elements in the industrial sector are compiled in Table 3-5. For the industrial sector, it is necessary to consider the same factors as in the case of the commercial sector. The difference is that visualization terminals for tenants, which are assumed for buildings and commercial facilities, and the demand response, which encourages home users to go to commercial facilities, are not considered in the industrial sector, which mainly assumes factories. Regarding the stakeholders in the industrial sector, facility managers of factories bear the costs.

Table 3-5 Cost elements possible in the industrial sector

Possible cost elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	Heat source facility	CGS (Cogeneration system)						○		○
			Conduit (for heat accommodation)					○		○
		Heat pump						○		○
		Others (ice storage, absorption type gas cooling, solar thermal, etc.)						○		○
	Photovoltaic power generation							○		○
	Battery (including hybrid battery)		Lead					○		○
			Lithium ion					○		○
			Redox flow					○		○
			NAS					○		○
	Management system	BEMS	Cloud type					○		○
			On-site installation type					○		○
	Smart facility		LED					○		○
			Air conditioner (including radiant heat)					○		○
			Others					○		○
	Water treatment facility	Service water treatment	Treatment facility					○		○
			Fresh water generation facility (desalination of seawater)					○		○
			Control system					○		○
		Wastewater treatment	Wastewater regeneration facility					○		○
			Control system					○		○
DR service	DR for negawatt trading	DR incentive	Calculated for the region/area sector	-	-	-	-	-	-	-
		Imbalance penalty charges	Calculated for the region/area sector	-	-	-	-	-	-	-

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , －: not applicable(N/A)

(Note) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(6) Demand side: Transport sector

The possible cost elements in the transport sector are compiled in Table 3-6. For the transport sector, it is necessary to consider the diffusion of smart facilities as well as that of demand response (DR) service, which is a service menu of aggregators including power retailers.

Table 3-6 Cost elements possible in the transport sector

Possible cost elements					Stakeholders						Application
					SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	Vehicle	Electric drive vehicle (EDV)	Hybrid electric vehicle (HEV)			○					○
			Plug-in hybrid electric vehicle (PHEV/PHV/PEV)			○					○
			Electric vehicle (EV/BEV)			○					○
		Hydrogen vehicle	Fuel-cell vehicle (FCV)			○					○
	Energy replenishment facility	Charging station	Charger	Normal charger		○		○			○
				Quick charger		○		○			○
				Subsidy		○					○
			Attached battery (including hybrid battery)	Lead		○		○			○
				Lithium ion		○		○			○
			Attached PV power generation facility			○		○			○
		One-way charger	For house							○	○
			For apartment house						○		○
			For building						○		○
			For factory						○		○
		Hydrogen station	Charging facility (dispenser)					○			○
			Subsidy			○					○
	V2X-dedicated facility	Two-way charger	For house (V2H)							○	○
			For apartment house (V2M)						○		○
			For building (V2B)						○		○
			For factory (V2F)						○		○
	Modal shift	Promotion of use of trains	Development and expansion of parking lot			○					-
			Development and expansion of bus network			○		○			-
				Bus		○		○			-
			Introduction of light rail transit (LRT)			○		○			-
		Promotion of sharing	Passenger car			○		○			-
			Motorcycle			○		○			-
			Bicycle			○		○			-
			Demand traffic	Shared taxi		○		○			-
				Welfare taxi		○		○			-

Table 3-6 Cost elements possible in the transport sector (Continued)

DR service	Traffic system	Traffic management system TDM (vehicle information management, starting DR, etc.)					○				○
		Visualization service (for users)					○				○
		Aggregate facility	On-board equipment (such as SOC control information)				○				○
			Charging station control system	For house			○				○
				For apartment house			○				○
				For building			○				○
				For factory			○				○
	V2X control system		For house (V2H)				○				○
			For apartment house (V2M)				○				○
			For building (V2B)				○				○
			For factory (V2F)				○				○
	DR incentive	For traffic control	Calculated for the region/area sector		-	-	-	-	-	-	-
		For V2X control	Calculated for the region/area sector		-	-	-	-	-	-	-

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , −: not applicable(N/A)

(Note) DR: Demand response; SH1: System operators; SH2: Country, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

The main elements of smart facilities in the transport sector are next-generation vehicles and energy replenishment facilities. These are considered as elements from the viewpoint of energy consumption. On the other hand, a utilization method called V2X, which considers and utilizes batteries mounted on next-generation vehicles as energy sources, is included in the possible elements. Furthermore, modal shift, which reduces energy consumption by changing the social structure, is considered in addition to efforts related to automobiles alone. Modal shift includes efforts to encourage automobile users to use public transportation and reduce the number of privately owned automobiles, and is considered to occur in smart communities.

The demand response (DR) service in the transport sector is classified into management for traffic reduction and management of automobile energy demand by the induction of each automobile. The latter management is particularly important since it is an unconventional method for reducing the influence on the power infrastructure because, unlike conventional consumers, automobiles consume energy while moving.

Regarding the stakeholders in the transport sector, unlike other sectors, power retailers bear the cost for demand response (DR) service, but other costs are borne by various stakeholders, mainly the country, economy, government, etc.

3-1-3 Benefit Elements Used for Evaluating Investment Value of Smart Communities

As described in Section 3-1-1, the benefits of a smart community are compiled from the viewpoint of the 3E approach (energy security, economic efficiency, and environmental conservation). Here, it should be noted that both the positive and negative effects of benefits must be considered. Therefore, evaluation of the investment value of a smart community means that of the balance between the costs and benefits. Depending on the stakeholder and purpose, some of the extracted benefits have different expressions, but the same contents. These are regarded as duplicate benefits, and therefore close examination is required. The benefit elements that contribute to the evaluation of the investment value of smart communities are described below for each sector.

(1) Supply side: Grid (power infrastructure)

The possible benefit elements on the grid side are compiled in Table 3-7. What is most important to consider is the extent to which electricity charges are reduced by the introduction of smart communities compared with the conventional power supply using only a grid.

Here, the benefit is classified into the electricity charge reduction effect and the fuel and light cost reduction effect because the former directly reduces electricity charges, but the latter is considered to contribute to the reduction of energy costs as a whole since some consumers use other heat sources such as gas and oil while saving electricity.

The stakeholders who enjoy the benefit are power retailers, who sell electricity, and facility managers and end users, who use electricity.

Table 3-7 Benefit elements possible on the grid side

Possible benefit elements		Stakeholders						Application
		SH1	SH2	SH3	SH4	SH5	SH6	
Electricity charges after introduction of smart community	Electricity charge reduction effect			○		○	○	○
	Fuel and light cost reduction effect					○	○	○

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable

(Note) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(2) Demand side: Region/area sector

The possible benefit elements in the region/area sector are compiled in Table 3-8. These include the benefits of private power generation facilities and demand response (DR) service, and also the benefits of water treatment facilities and water demand response (DR) service with regard to efforts related to water.

From the viewpoint of energy security, benefits for the continuance and stabilization of life and economic activity represented by the energy self-sufficiency rate in the region are included as well as the benefit of demand response (DR) service introduced by system operators as a system measure for weather-dependent renewable energy. From the viewpoint of economic efficiency, monetary benefits represented by FIT income and the electricity charge reduction effect and the benefit of efficient use of energy represented by the energy saving effect are included. From the viewpoint of environmental conservation, benefits related to the natural environment, such as reduction of CO_2 emissions and pollution control, are included.

Table 3-8 Benefit elements possible in the region/area sector

Possible benefit elements					Stakeholders						Application
					SH1	SH2	SH3	SH4	SH5	SH6	
Private power generation facility	Power source development			Nature destruction due to construction		○					-
				Living standard improvement effect		○					-
	Power accommodation	Power selling to power companies		FIT income			○				○
		Regional use	Reduction of system power purchase	Energy self-sufficiency rate improvement effect		○					○
				Electricity charge reduction effect *1					○		○
				Fuel and light cost reduction effect *1						○	○
				Energy-saving effect of installation *2			○				○
				CO_2 reduction effect of installation *2,*a			○				○
				CO_2 credit due to installation *a		○					○
			Operation/ maintenance of private facilities	Regional employment creation effect		○					○
	Heat accommodation	Regional use	Reduction of system power purchase	Energy self-sufficiency rate improvement effect		○					○
				Electricity charge reduction effect *3					○		○
				Fuel and light cost reduction effect *3						○	○
				Energy-saving effect of installation *4			○				○
				CO_2 reduction effect of installation *4,*b			○				○
				CO_2 credit due to installation *b		○					○
			Operation/ maintenance of private facilities	Regional employment creation effect		○					○
	Ancillary measures		Battery for community	Power quality stabilizing effect	○						○

Table 3-8 Benefit elements possible in the region/area sector (Continued)

DR service	DR by system operators		Effect of decreasing margin of regulated power supply	○						○
			Reduction of procured power supply cost	○						○
	DR by power retailers/ PPS/ aggregators	With or without negawatt trading	Regional economic ripple effect		○					○
			Energy-saving effect of DR *5			○				○
			CO_2 reduction effect of DR *5,*c			○				○
			CO_2 credit due to DR *c		○					○
			Regional value improvement effect *d		○					○
			Comfort effect *d						○	○
			Customer corralling effect *d			○				○
		Negawatt trading available	Negawatt revenue			○				○
		No negawatt trading	Efficient energy use effect *5			○				○
Water treatment facility	Water purification plant, fresh water generation facility (for desalination of seawater), wastewater regeneration treatment		Corporate activity improvement effect				○			○
			Living standard improvement effect						○	○
	Wastewater treatment plant (for household wastewater), wastewater treatment facility (for industrial wastewater)		Pollution control effect		○					○
			Health and sanitation improvement effect						○	○
	Water storage facility		Urban disaster prevention (BCP) effect		○					○
Water DR service	Water saving (water cutoff) DR		Living standard ensuring effect		○				○	○
	Water quantity adjustment DR		Urban disaster prevention (BCP) effect		○				○	○
	Power saving DR		Calculated for the commercial sector and industrial sector	-	-	-	-	-	-	-

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , −: not applicable(N/A)

(Note 1) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(Note 2) The same "* number" indicates benefits calculated from the same measurement value, and the same "* letter" indicates the same benefit from different viewpoints.

There are also other benefit elements brought by the introduction of a smart community in the region/area sector from viewpoints other than 3E above. Specifically, benefits promoting regional revitalization represented by the creation of regional employment and the improvement of regional brands, life benefits represented by the improved standard of living and measures involving water storage facilities against urban disasters, and corporate benefits for companies providing smart communities as part of their customer service are included in possible benefits. Given the various benefit elements as described above, there are also various stakeholders.

(3) Demand side: Residential sector

The possible benefit elements in the residential sector are compiled in Table 3-9. Here, there are two benefits: that of smart facilities and that of demand response (DR) service. From the viewpoint of energy security, benefits for maintaining quality of life (QOL) even at the time of a power outage, represented by batteries, and the benefit of home demand response (DR) service on the grid side are included. From the viewpoint of economic efficiency, monetary benefits represented by the fuel and light cost reduction effect and the benefit of efficient use of energy represented by the energy saving effect are included. From the viewpoint of environmental conservation, benefits related to the natural environment, such as reduction of CO_2 emissions, are included. For example, zero energy homes (ZEH) are considered from the viewpoints of both economic efficiency and environmental conservation.

There are other viewpoints in addition to 3E in the residential sector. Benefits to meet system operators' needs, benefits brought by providing smart houses for building fascinating towns, and corporate benefits for companies providing smart communities as part of their customer service are included in the possible benefits. Benefit elements for which the effects are difficult to calculate are not subject to numerical determination. Stakeholders in the residential sector include not only the selling side and buying side of electricity, but also the country economy, and government.

Table 3-9 Benefit elements possible in the residential sector

Possible benefit elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	System operator facility	Smart meter	Cost reduction effect	○						-
			CO_2 reduction effect of visualization	○						○
			Industrial accident reduction effect	○						-
	End user facility	Common to facilities (photovoltaic power generation facility, heat pump, fuel cell, battery, smart appliance, etc.)	Fuel and light cost reduction effect						○	○
			Energy-saving effect of installation *1		○					○
			CO_2 reduction effect of installation *1,*a		○					○
			CO_2 credit due to installation *a		○					○
			Regional value (charm) improvement effect		○					○
		Battery for home use	Disaster prevention (BCP) effect						○	○
	Facilities subject to DR	Visualization terminal	Energy-saving effect of visualization *2			○				○
			CO_2 reduction effect of visualization *2,*b			○				○
			CO_2 credit due to visualization *b		○					○
DR service	DR by system operators		Electricity saving (peak cut) effect *3	○						○
			Ancillary measure effect *3	○						○
			Fuel and light cost reduction effect						○	○
			Energy-saving effect of DR *4	○						○
			CO_2 reduction effect of DR *4,*c	○						○
			CO_2 credit due to DR *c	○						○
	DR by power retailers/PSS/ aggregators		Negawatt revenue			○				○
			Fuel and light cost reduction effect						○	○
			Energy-saving effect of DR *5			○				○
			CO_2 reduction effect of DR *5,*d			○				○
			CO_2 credit due to DR *d			○				○
			Customer corralling effect			○				○
			Customer satisfaction improvement effect						○	-

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , −: not applicable(N/A)

(Note 1) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(Note 2) The same "* number" indicates benefits calculated from the same measurement value, and the same "* letter" indicates the same benefit from different viewpoints.

(4) Demand side: Industrial sector

The possible benefit elements in the industrial sector are compiled in Table 3-10. Here, there are two possible benefit elements: that of smart facilities and that of demand response (DR) service. The same 3E viewpoints and the same stakeholders as those in the commercial sector also apply to the industrial sector with the exception of efforts made for commercial facilities, where the only difference is whether the target is buildings or factories.

Table 3-10 Benefit elements possible in the industrial sector

Possible benefit elements				Stakeholders						Application
				SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	Factory manager facilities	CGS (cogeneration system)	Disaster prevention (BCP) effect					○		○
		Common to facilities (CGS, heat pumps, other heat source facilities, photovoltaic power generation facilities and smart facilities (LED, etc.))	Factory cost reduction effect					○		○
			Energy-saving effect of installation *1					○		○
			CO_2 reduction effect of installation *1,*a					○		○
			CO_2 credit due to installation *a		○					○
		Management system (FEMS)	Factory cost reduction effect					○		○
			Energy-saving effect of EMS *2					○		○
			CO_2 reduction effect of EMS *2,*b					○		○
			CO_2 credit due to EMS *b		○					○
	Facilities subject to DR	Visualization terminal (for office)	No benefit is yielded by facilities alone.	-	-	-	-	-	-	-
DR service	Negawatt trading		Negawatt revenue			○				○
			Energy-saving effect of DR *3			○				○
			CO_2 reduction effect of DR *3,*c			○				○
			CO_2 credit due to DR *c		○					○

Source: Institute of Energy Economics, Japan Remarks; ○:Applicable , －: not applicable(N/A)

(Note 1) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(Note 2) The same "* number" indicates benefits calculated from the same measurement value, and the same "* letter" indicates the same benefit from different viewpoints.

(5) Demand side: Transport sector

The possible benefit elements in the transport sector are compiled in

Table 3-11. Here, as with the other sectors, there are two possible benefit elements: that of smart facilities and that of demand response (DR) service. In the transport sector, the concept of benefit elements from the 3E viewpoints is the same as in the other sectors; however, consideration is also given to benefit elements other than energy, such as road traffic congestion mitigation effect, traffic accident reduction effect and noise reduction effect. Given the various benefit elements as described above, there are also various stakeholders.

Table 3-11 Benefit elements possible in the transport sector

Possible benefit elements					Stakeholders						Application
					SH1	SH2	SH3	SH4	SH5	SH6	
Smart facility	Automobile alone	Common to car bodies (electric drive vehicle, hydrogen vehicle)		Maintenance cost reduction effect						○	○
				Energy-saving effect of introduction *1				○			○
				CO_2 reduction effect of introduction *1,*a				○			○
				Brand image improvement effect				○			○
		Electric vehicle and fuel-cell vehicle		Air pollution control effect *a		○					○
	Energy replenishment facility	Charging/ hydrogen station and charger		No benefit is yielded by facilities alone.							-
	V2X-dedicated facility	Two-way charger		Disaster prevention (BCP) effect					○	○	○
	Modal shift	Promotion of use of trains		Household cost reduction effect		○				○	-
				Energy-saving effect of use *2		○				○	-
				CO_2 reduction effect of use *2,*b		○				○	-
				Air pollution control effect *b		○				○	-
				Road traffic congestion mitigation effect		○				○	-
				Traffic accident reduction effect		○				○	-
				Noise reduction effect		○				○	-
		Promotion of sharing	Automobile, motorcycle, bicycle	Household cost reduction effect						○	-
				Energy-saving effect of use *3		○					-
				CO_2 reduction effect of use *3,*c		○					-
				Air-pollution control effect *c		○				○	-
			Motorcycle, bicycle, demand traffic	Convenience effect						○	-
			Motorcycle, bicycle	Road traffic congestion mitigation effect		○				○	-
			Bicycle	Traffic accident reduction effect		○				○	-
				Noise reduction effect		○				○	-

Table 3-11 Benefit elements possible in the transport sector (Continued)

DR service	Traffic control system	Disaster prevention (BCP) effect					○		○
		Load leveling effect *4			○				○
		Demand promotion effect (absorption of surplus PV, etc.) *4			○				○
		Electricity saving effect *4,*5 (demand for charging, utilization of surplus PV, etc.)			○				○
		Negawatt revenue			○				○
		Posiwatt revenue			○				○
		Fuel cost reduction effect						○	○
		Energy-saving effect of DR *5,*6	○						○
		CO_2 reduction effect of DR *6,*d	○						○
		CO_2 credit due to DR *d	○						○
		Road traffic congestion mitigation effect	○						○
	V2X control system	Disaster prevention (BCP) effect					○		○
		Price of DR						○	○
		Energy-saving effect of DR *7		○					○
		CO_2 reduction effect of DR *7,*e		○					○
		CO_2 credit due to DR *e		○					○

Source: Institute of Energy Economics, Japan　　Remarks; ○:Applicable , －: not applicable(N/A)

(Note 1) DR: Demand response; SH1: System operators; SH2: Country, economy, government, etc.; SH3: Power retailers; SH4: Other companies; SH5: Facility managers; SH6: End users

(Note 2) The same "* number" indicates benefits calculated from the same measurement value, and the same "* letter" indicates the same benefit from different viewpoints.

3-1-4 Discussion

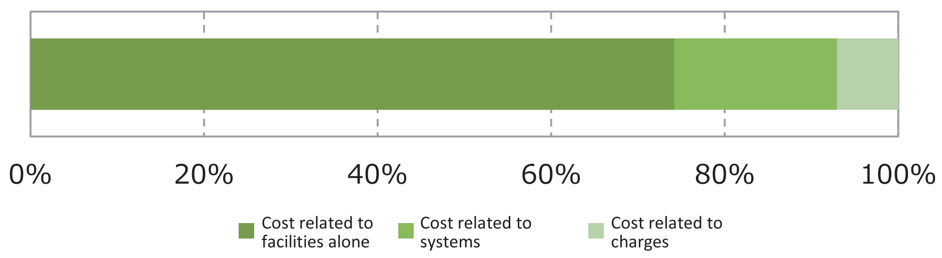
In theory, the above-described cost and benefit elements obtained by using a static framework should be discussed based on the results of CBR and/or NPV, which are value evaluation methods for smart communities, but in this study, they are simply discussed based on the number of compiled elements as follows.

(1) Cost element analysis

Classifying the possible cost elements in the construction of a smart community into "those related to facilities alone", "those related to systems" and "those related to charges" means that "Cost related to facilities alone" accounts for a little over 70%, "that related to systems", 20%, and "that related to charges", a little under 10%, as shown in Figure 3 2.

This means that there are not many investment elements in relation to systems or charges; however, investment in the facilities themselves is the key to the diffusion of smart communities.

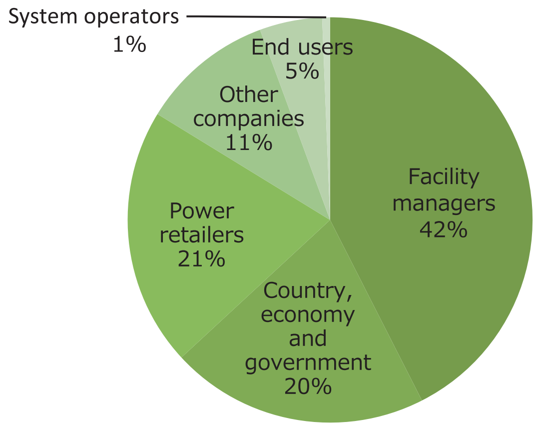
Figure 3-2 Percentages of possible cost items in the construction of a smart community



Source: Institute of Energy Economics, Japan

Regarding defrayers, as shown in Figure 3-3, facility managers of buildings and/or factories account for a little over 40%, and the country/economy/government and power retailers account for 20% each. This means that the most important consideration is the promotion of investment in the commercial and industrial sectors. In addition, ready-to-implement policies are required for the country/economy/government and power retailers.

Figure 3-3 Defrayers of possible cost items in the construction of a smart community

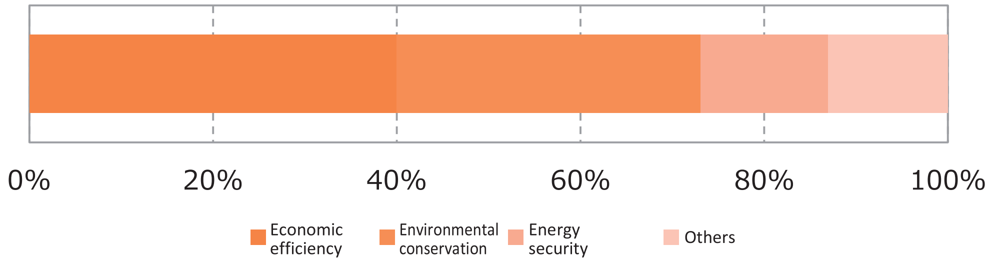


Source: Institute of Energy Economics, Japan

(2) Benefit element analysis

Classifying the possible benefit elements in the construction of a smart community into “economic efficiency”, “environmental conservation”, “energy security” and “others”, the first accounts for 40%, the second, a little over 30%, and the third and fourth, a little over 10% each, as shown in Figure 3-4. This means that attention is mainly paid to the benefit of smart communities from the viewpoints of economic efficiency and environmental conservation.

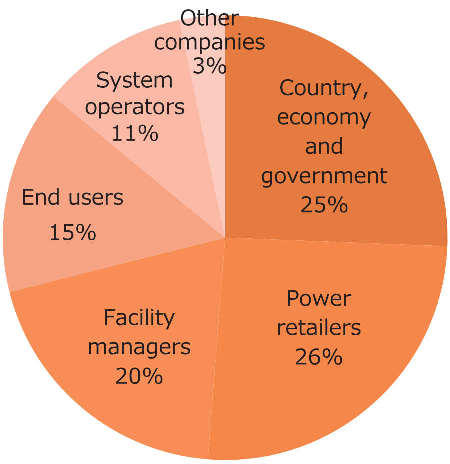
Figure 3-4 Percentages of possible benefit elements in the construction of a smart community



Source: Institute of Energy Economics, Japan

Regarding beneficiaries, the country/economy/government and power retailers account for a little below 30% each, facility managers, 20%, and end users and system operators, a little over 10% each, as shown in Figure 3-5. This means that the trend in the country/economy/government and power retailers is the key to the diffusion of smart communities while ready-to-implement policies and field development are required.

Figure 3-5 Percentages of possible benefit elements in the construction of a smart community

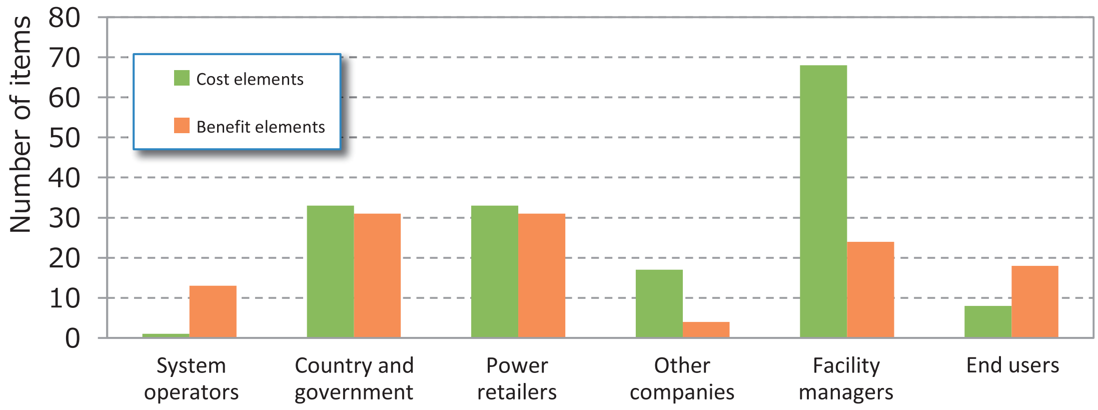


Source: Institute of Energy Economics, Japan

(3) Comparison of cost benefit elements

Figure 3-6 shows a comparison of the compiled cost and benefit elements among the stakeholders.

Figure 3-6 Comparison of the number of possible cost and benefit elements in the construction of a smart community



Source: Institute of Energy Economics, Japan

The comparison shows that system operators and end users have more benefit items than cost items in the construction of a smart community. This is because the influence on the grid side is reduced by managing unstable elements, such as renewable energy, in smart communities, which benefits the system operators and is the purpose of smart communities for the end users.

On the other hand, facility managers and other companies have fewer benefit items than cost items. This suggests that the small benefit for investment is an obstacle to the diffusion of smart communities. For the country/economy/government and power retailers, there are slightly fewer benefit elements than cost elements, but there is a possibility that an effect will meet the investment requirements.

Thus, the comparison between the number of cost and benefit elements suggests that it is necessary to support the country/economy/government and power retailers in the diffusion of smart communities while supporting the facility managers in terms of costs.

This study discusses cost and benefit elements focusing on their number, but in reality, the investment value of smart communities should be determined based on the effect evaluation using CBR, NPV, or the like. It is necessary to convert the cost and benefit elements extracted in this study into monetary values and quantitatively evaluate them one by one in the future. At that time, the evaluation of a smart community as a whole is important, but equally important is stepwise evaluation of the power infrastructure depending on the degree of development, local evaluation of cities, rural areas, islands, etc., and evaluation of specific stakeholders clarified in this study when determining the policy for the diffusion of a smart community.

3-2 Creation and Discussion of Dynamic Frameworks

3-2-1 Compilation of stages and elements for the creation of dynamic frameworks

Section 3-1 described the “static framework”, which comprehensively compiles the elements of a smart community regardless of the status of power infrastructure development, as an evaluation framework for smart communities. This section describes the “dynamic framework”, which classifies the target countries into those in the development stage, the transition stage, and the mature stage based on the economic scale and the status of power infrastructure development, and then compiles the elements of a smart community at each stage.

Unlike static frameworks, which comprehensively evaluate values, dynamic frameworks extract the cost and benefit elements of a smart community at each stage of power infrastructure development, and then evaluate the investment value of a smart community using CBR and/or NPV. Here, prior to extracting the costs and benefits at each stage of development, the 21 APEC countries are classified by their stage of development considering the economic scale and the status of power infrastructure development, and then examples of efforts related to smart communities are compiled at each stage. Regarding the classification of stages, it is appropriate to use indices related to the power infrastructure, such as the power outage rate and electrification rate in principle, but this study simply classifies the APEC countries into developed countries, emerging countries (G20 countries except developed countries) and developing countries as specified by IMF. The number of examples of smart communities used for the compilation is shown for each country or economy in Table 3-12.

Table 3-12 Classification of countries by the stage of power infrastructure development and the number of examples of smart communities

Stage of power infrastructure development	Country or economy	Number of examples	Subtotal
Development stage (9 countries)	Brunei	2	40
	Malaysia	5	
	The Philippines	5	
	Thailand	5	
	Viet Nam	7	
	Papua New Guinea	1	
	Indonesia	6	
	Chile	4	
	Peru	5	
Transition stage (6 countries)	China	16	35
	Hong Kong, China	3	
	Chinese Taipei	6	
	Russia	6	
	Mexico	4	
Mature stage (7 countries)	Japan	6	57
	The United States	15	
	Canada	11	
	Australia	10	
	New Zealand	7	
	Singapore	3	
	Korea	5	
Total			132

Source: APERC (2015)

3-2-2 Compilation of Examples of Efforts Related to Smart Communities Depending on the Stage of Power Infrastructure Development

While Chapter 1 describes the general role of a smart community depending on the stage of development of the power infrastructure, this section builds a hypothesis about the specific role of a smart community at each stage of development, and then clarifies the specific elements of a smart community at each stage by compiling the above-described examples of efforts related to smart communities at each stage. Table 3-13 shows the hypothesis on the specific role of a smart community at each stage of power infrastructure development.

Table 3-13 Role of smart communities depending on the stage of power infrastructure development

Stage of development	Role of smart community		
	Infrastructure development	Creation of smart communities	Development into further fields
Development stage	The main purpose is the construction of social infrastructure (e.g., power generation, power, water, traffic, communication, waste treatment and crime prevention infrastructure) mainly in major cities and industrial development areas. (Elemental, quantitative expansion)	Gradually expands from monitoring of various information to incorporation of energy creation (photovoltaic power generation) as power generation facilities.	-
Transition stage	Expands the social infrastructure from major cities to rural areas while gradually sophisticating the facilities. Expands to environmental care in some countries. (Shift from elements to the whole and from quantity to quality)	Expands from the incorporation of energy creation to that of a part of energy storage. Energy management utilizing ICT gradually expands in some countries.	-
Mature stage	Scales down centralized power plants (Decentralization or electricity saving, downsizing, etc.) and reorganizes the social infrastructure and structure considering environmental conservation. (Enhancement of quality)	Incorporates energy creation, energy saving and energy storage while conducting energy management utilizing ICT.	Promotes technical innovation and develops new business for the creation of new added value through the creation of smart communities.

Source: Institute of Energy Economics, Japan

Table 3-14 shows examples of efforts related to smart communities at each stage of power infrastructure development, which are compiled based on the examples of smart communities in the 21 APEC countries.

The most common example of efforts in the development stage is “development of the power system”, followed by “introduction of energy creating facilities such as photovoltaic power generation facilities” and “introduction of power saving facilities such as electric vehicles in the traffic sector”, in that order. Furthermore, “installation of power generation facilities” and “crime prevention in towns” are more common in this stage among the three stages of power infrastructure development. On the other hand, “creation of customer value” is the least common in the development stage, followed by “energy saving in factories and water facilities” and “introduction of facility management in factories, water facilities and the traffic sector”, in that order.

The most common example of efforts in the transition stage is “development of the power system”, followed by “introduction of energy saving facilities in the traffic sector” and “introduction of energy creation”, in that order. Furthermore, “development of communication networks”, “introduction of facility management in the traffic sector” and “creation of customer value utilizing ICT” is more common in this stage than in the development stage. On the other hand, “development of crime prevention” and "introduction of facility management in factories and water facilities” are not common in the transition stage.

Table 3-14 Distribution of examples of efforts related to smart communities depending on the stage of power infrastructure development

Stage of development	Construction and development of social infrastructure							Introduction of energy creation, saving, and storage facilities								Introduction of facility management						Renovation	
									Energy saving (by facilities alone)														
	Power generation facility	Power system	Water network/ flood control	Traffic network	Communication network	Waste treatment	Crime and disaster prevention	Energy creation	Region	Houses	Buildings	Factories	Traffic	Water	Energy storage	Region	Houses	Buildings	Factories	Traffic	Water	Sophistication of facilities	Creation of customer value
Development stage	4%	16%	4%	4%	4%	3%	4%	15%	0%	2%	5%	1%	10%	1%	6%	5%	5%	4%	2%	1%	1%	5%	0%
Transition stage	1%	18%	3%	4%	8%	2%	0%	10%	0%	3%	5%	1%	12%	1%	1%	3%	5%	3%	0%	8%	0%	6%	4%
Mature stage	0%	6%	0%	0%	4%	0%	2%	25%	0%	13%	6%	0%	16%	0%	14%	2%	24%	11%	6%	10%	0%	23%	5%

Source: Institute of Energy Economics, Japan

(Note) The number of examples is as follows: N = 132 examples (Development stage: 40; Transition stage: 35; Mature stage: 57)

The examples of efforts in the mature stage are mainly “introduction of energy creation”, “facility management in the residential sector” and “sophistication of facilities such as power facilities”. Furthermore, “introduction of energy storage facilities” and “creation of consumer value” are most common in this stage among the three stages of power infrastructure development. On the other hand, there are few examples of efforts related to “construction and development of the social infrastructure” in the mature stage.

3-2-3 Discussion

This section discusses the hypothesis on the role of a smart community depending on the stage of development of the power infrastructure as described above and also examines the results of compiling the examples of efforts.

As the hypothesis suggests, a smart community is considered to be utilized mainly for the “construction and development of the social infrastructure”, and eventually the “introduction of energy creation”, in the development stage. Therefore, as shown by the results of compiling the examples, the “introduction of energy saving facilities” and “introduction of facility management” do not make much progress in the development stage. However, although the hypothesis does not suggest the level of the “introduction of energy saving facilities in the traffic sector”, as represented by the diffusion of smartphones in developing countries, diffusion is accelerated with demand even in the undeveloped stage of the social infrastructure. Therefore, the next-generation vehicles such as electric vehicles may become an important element of a smart community in the development stage.

Regarding the role of a smart community in the transition stage, considering the fact that the rate of “sophistication of facilities” increases while that of “development of the power system” remains high from the development stage, the “expansion from elements to the whole and shift from quantity to quality” are considered to occur, as suggested by the hypothesis. There are fewer examples of “introduction of energy saving facilities” and “introduction of facility management” in the transition stage, as with the development stage, but considering the high rate of “development of communication networks,” this stage is considered as the preparation stage for efforts utilizing ICT.

Regarding the role of a smart community in the mature stage, considering the fact that there are many examples of “introduction of energy creating facilities”, “introduction of energy saving facilities in the residential and traffic sectors” and “introduction of facility management in each sector,” the decentralization of centralized power plants and the efficient use of energy in decentralized areas are considered to be in progress, as the hypothesis suggests. Also, considering that there are many examples of “sophistication of facilities” and “creation of consumer value”, the development of a smart community in the mature stage is considered to enhance the quality while creating new innovation.

Next, we reclassify the above-described results of compiling from the viewpoints of “energy security”, “economic efficiency”, “environmental conservation” and “others”, and then discuss the results. The results of reclassification are shown in Table 3-15. As the hypothesis suggests, the role and purpose of a smart community gradually shift from energy security to economic efficiency, then to achievement of environmental objectives and creation of new economic value along with the stage of development of the power infrastructure.

Table 3-15 Role of smart communities depending on the stage of power infrastructure development

Stage of power infrastructure development	Energy security		Economic efficiency		Environmental conservation	Creation of other new values
	Construction of life infrastructure	Control/ suppression	Supplier	Consumer		
Development stage	○		○		△	
Transition stage	○	△	○		△	△
Mature stage		○		○	○	○

Source: Institute of Energy Economics, Japan

Based on the above discussion, to evaluate the investment value of a smart community, it is necessary to compile the costs and benefits of the smart community depending on the stage of development of the infrastructure and considering the purpose of investment as well as the social role. Consequently, it should be noted that it may not be appropriate to apply the elements of a smart community in the mature stage directly to the development or transition stage. Therefore, it is also important to clarify the stakeholders of the benefits of the smart community at each stage of development and share the strategy among the relevant parties when determining the policy for the diffusion of the smart community.

This section successfully suggests the importance of evaluating the investment value of smart communities using dynamic frameworks with a small number of examples of smart communities and simply classified stages of power infrastructure development. It is necessary to clarify the costs and benefits of smart communities depending on the stage of development of the power infrastructure by analyzing more examples while establishing the effect evaluation methods based on CBR and/or NPV. Furthermore, this study mainly handles examples in urban areas, but the elements required of smart communities are not necessarily the same in rural areas or islands. Therefore, it is also necessary in the future to clarify what is required of smart communities depending on the characteristics of the region, such as an urban area, rural area and island at each stage of power infrastructure development.

Chapter 4　Preliminary Study for the Evaluation of Smart Communities Using Optimal Power Generation Mix Model

4-1　Introduction

The previous chapter shows that the scope of smart community varies by region, and also shows that there are various stakeholders. Among the stakeholders, this chapter focuses on electricity sector (smart grid), and conduct a preliminary study on analytical methods for smart grid assessments. One of the purposes of a smart grid is to improve the stability and economic efficiency of power systems through demand responses. We discuss the effect of demand response, especially electricity saving, on the whole power system, considering the characteristics of each demand sector.

There have been various studies about the benefits of a smart grid. However, most of them have focused on the “grid stability” and specific technologies or sectors, but only a few studies have focused on the economic benefits of the whole power system. For instance, Ota, et al. (2011), Masuta, et al. (2012) and Kikuchi, et al. (2015) conducted simulations from frequency control perspectives, not from economic perspectives. Takagi (2010) and Ikegami (2010) analyzed the cost and benefit of smart grid technologies using a least-cost model. However, the former focuses only on electric vehicles, and does not consider demand responses. The latter consider various demand side technologies; but, its analysis covers only residential sector, not the whole power system.

Therefore, this chapter discusses a power generation mix model considering demand responses as well as the characteristics of demand sectors. We develop a preliminary model which takes into account price elasticity of electricity consuming sectors, such as residential, commercial and industry sectors. This chapter also conducted a trial analysis of the effect of the demand response (electricity saving, in particular) on the power system. Section 4-2 provides an outline of the optimal power generation mix model, and Section 4-3 describes the details of the model structure and input data assumptions. Section 4-4 is about the simulation case settings, results and the discussion.

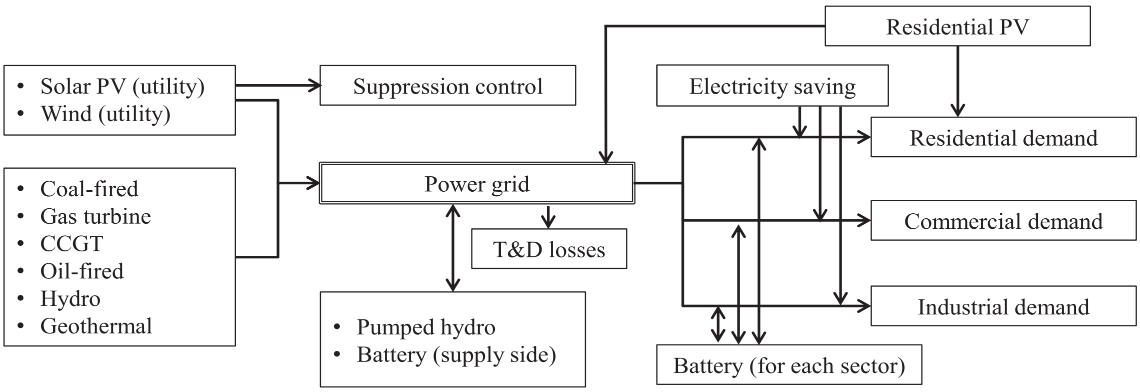
4-2 Method: Optimal Power Generation Mix Model Considering Electricity Saving

4-2-1 Outline of Model

The optimal power generation mix model (Figure 4-1) used in this study is the least-cost linear programing model. The objective function is the sum of the costs for power generation, power storage and electricity saving. The feature of this model is the division of the electric power load among sectors. Whereas many existing studies[3] used only the integrated sectoral load or the load curve of a specific sector, this study divides the load into each sector to explicitly consider load characteristics (price elasticity, load curve, etc.) can be considered within the model.

The model considers eight power generation technologies (coal-fired, gas turbine, combined cycle gas turbine, oil-fired, hydro, geothermal, wind and photovoltaics) on the supply side as well as two power storage technologies (pumped hydro and battery). On the demand side, power generation technology residential photovoltaics (PV) and batteries are considered in this study.

Figure 4-1 Outline of the optimal power generation mix model



Source: APERC analysis.

4-2-2 Modeling of Load Leveling

Load and net load[4] are expected to be leveled by demand responses by smart grid. Consequently, expected benefits for supply side (power companies, etc.) include a reduction of peaking plants and an improvement of the utilization rate of base and middle load plants due to the increasing load factor. Improved economic efficiency would result in benefiting the demand-side as well, for example, by curbing electricity charges. Load leveling measures are also expected to benefit to variable renewables integration. Large-scale variable renewables causes a steep net load due to short-term and/or diurnal fluctuation. This effect may be mitigated by demand-side measures, such as

[3] For instance, Ikegami, et al. (2010), Komiyama, et al. (2015), and Otsuki, et al. (2016).

[4] Load minus power generation from renewable energy.

demand shift and electricity saving (Figure 4-9). Our model considers both demand shift and electricity saving as mentioned below. Here, the demand shift means shifting the time zone where electricity is used, and the electricity saving means reducing the power consumption itself.

Demand shift includes the utilization of energy storage (the battery on the demand side, etc.) and the use of electric equipment activated through information communication equipment or HEMS/BEMS equipment. Storage technologies are expected to level the electric load by charging electricity when surplus electricity is available, and by discharging electricity at the peak time, similar to conventional pumped hydro power generation. Activated electric equipment is expected to operate automatically avoiding the peak load time, consequently reducing peak load as well as pushing up base and middle load. This study includes the demand-side battery system. The shift in the use time of electric equipment is not considered in this study, but is left for future discussion.

We modeled electricity saving in a top-down manner (Section 4-3). This study assumes that electricity savings reduce consumer utility, and estimates the cost of electricity saving based on the loss of consumer utility. The model determines the amount of savings by comparing the cost for power generation/storage and the loss of consumer utility due to electricity saving.

4-3 Formulation and Input Data

4-3-1 Mathematical formulation

This section describes the mathematical formulation of the model. Table 4-1 provides the definitions of endogenous variables and indices. This model is a single-region model with three demand sectors (residential, commercial and industrial). Regarding the temporal resolution, the model considers the hourly load curves of typical days for three seasons (summer, winter and intermediate season). Thus, one calendar year is decomposed into 72 segments (3 seasons × 1 representative day per season × 24 time slices per day).

Table 4-1 Definitions of endogenous variables and indices

Endogenous variable and index	Description
TC	Total system cost [USD/year]
$nld_{d,s,t}$	Load on sector *d*, in season *s*, at time *t* (load minus the output of demand-side renewables, net discharge of demand-side batteries, and electricity saving) [GW]
$xp_{p,s,t}$	Output of power generation technology *p* in season *s*, at time *t* [GW]
$mp_{p,s}$	Maximum daily output of power generation technology *p* [GW] (*p* = thermal power generation)
$de_{p,s,t}$	Suppression control of power generation technology *p* in season *s*, at time *t* [GW] (*p* = wind, PV on the system side)
$dtg_{s,t}$	Residential PV output supplied into power grid in season *s*, at time *t* [GW]
$dtd_{s,t}$	Residential PV output consumed at demand side in season *s*, at time *t* [GW]
$ded_{s,t}$	Suppressed residential PV in season *s*, at time *t* [GW]
kp_{p}	Capacity of power generation technology *p* [GW]
$xi_{c,s,t}$	Electricity charge of supply-side storage technology *c* in season *s*, at time *t* [GW]
$xo_{c,s,t}$	Electricity discharge of supply-side storage technology *c* in season *s*, at time *t* [GW]
$xid_{d,cd,s,t}$	Electricity charge of demand-side storage technology *cd* in sector *d*, in season *s*, at time *t* [GW]
$xod_{d,cd,s,t}$	Electricity discharge of demand-side storage technology *cd* in sector *d*, in season *s*, at time *t* [GW]
$sc_{c,s,t}$	Stored electricity of supply side storage technology *d* in season *s*, at time *t* [GWh]
$scd_{d,cd,s,t}$	Stored electricity of demand-side storage technology *cd* n sector *d*, in season *s*, at time *t* [GWh]
kc_{c}	Installed capacity of supply-side storage technology *c* [GW]
$kcd_{d,cd}$	Installed capacity of demand-side storage technology *cd* in sector *d* [GW]
$xv_{d,v,s,t}$	Electricity saving variable in sector *d*, in season *s*, at time *t*
Index	
s	Season (1: summer, 2: winter, 3: intermediate season)
t	Time (0, 1, 2, ⋯, 23)
d	Demand sector (1: home, 2: business, 3: industry)
p	Power generation technology (1: nuclear, 2: coal-fired, 3: natural gas combined cycle, 4: natural gas turbine, 5: oil-fired, 6: hydro, 7: geothermal, 8: wind, 9: PV on the system side, 10: PV for home use)
c	Supply-side storage technology (1: pumped hydro power generation, 2: battery)
cd	Demand-side storage technology (1: battery)
v	Electricity saving index (0, 1, ⋯, 9)

Source: APERC analysis.

(1) Objective function

Eq. 4-1 is the objective function. This model minimizes total system cost for a single year. This mode minimizes total system cost for a single representative year. The objective function is composed of power generation cost, storage cost and electricity saving cost (loss of consumer utility). Here, the construction cost *CI*, fuel cost *CF* (only for power generation technology), operation and maintenance (O&M) cost *CO*, and carbon cost *CC* are considered as the costs for power generation and power storage (for the estimation of the electricity saving cost *CV*, refer to Eq. 4-34 to Eq. 4-40). The annual construction cost is calculated by multiplying the amount of investment by the capital recovery factor. The capital recovery factor is calculated from the interest rate and the number of utilization years of each technology. The assumed number of utilization years of each technology is shown in Section 4-3-2, where the interest rate is assumed to be 3%.

$$min.TC = CI + CO + CF + CC + CV \quad \text{Eq. 4-1}$$

$$CI = \sum_{p} PA_p \cdot PI_p \cdot kp_p + \sum_{c} CA_c \cdot CI_c \cdot kc_c + \sum_{d}\sum_{cd} CDA_{d,cd} \cdot CDI_{d,cd} \cdot kcd_{d,cd} \quad \text{Eq. 4-2}$$

$$\begin{aligned} CO = &\sum_{p}\left(POF_{n,p} \cdot kp_p + \sum_{s}\sum_{t} POV_p \cdot xp_{p,s,t} \cdot HW_{s,t}\right) \\ &+ \sum_{c}\left(COF_c \cdot kc_c + \sum_{s}\sum_{t} COV_c \cdot xi_{c,s,t} \cdot HW_{s,t}\right) \\ &+ \sum_{d}\sum_{cd}\left(CDOF_{cd} \cdot kcd_{d,cd} + \sum_{s}\sum_{t} COV_{cd} \cdot xid_{d,cd,s,t} \cdot HW_{s,t}\right) \end{aligned} \quad \text{Eq. 4-3}$$

$$CF = \sum_{p}\sum_{s}\sum_{t} PF_p \cdot xp_{p,s,t} \cdot HW_{s,t} \quad \text{Eq. 4-4}$$

$$CC = \sum_{p}\sum_{s}\sum_{t} CTAX \cdot Carbon_p \cdot xp_{p,s,t} \cdot HW_{s,t} \quad \text{Eq. 4-5}$$

$$CV = \sum_{d}\sum_{v}\sum_{s}\sum_{t} VC_{d,v,s,t} \cdot LDC_{d,s,t} \cdot xv_{d,v,s,t} \cdot HW_{s,t} \quad \text{Eq. 4-6}$$

$$HW_{s,t} = 8760 \cdot {}^{LGM_s}/_{12} \cdot {}^{LGT_t}/_{24} \quad \text{Eq. 4-7}$$

CI: Annual construction cost [USD/year], ***CO***: Annual operation and maintenance cost [USD/year], ***CF***: Annual fuel cost [USD/year], ***CC***: Annual carbon cost [USD/year], ***CV***: Electricity saving cost [USD/year], PA_p: Capital recovery factor of power generation technology *p*, PI_p: Construction cost for power generation technology *p* [USD/kW], CA_c: Capital recovery factor of supply-side storage technology *c*, CI_c: Construction cost of supply-side power storage technology *c* [USD/kW], $CDA_{d,cd}$: Capital recovery factor of demand-side storage technology *cd* in sector *d*, $CDI_{d,cd}$: Construction cost for demand-side storage technology *cd* in sector *d* [USD/kW], POF_p: Fixed operation and maintenance cost for power generation technology *p* [USD/kW/year], ***POV$_p$***: Variable operation and maintenance cost for power generation technology *p* [USD/kWh], ***COF$_c$***: Fixed operation and maintenance cost for supply-side storage technology *c* [USD/kW/year], ***COV$_c$***: Variable operation and maintenance cost for supply-side storage technology *c* [USD/kWh], ***CDOF$_{cd}$***: Fixed operation and maintenance cost for demand-side storage technology *cd* in sector *d* [USD/kW/year], ***CDOV$_{cd}$***: Variable operation and maintenance cost for demand-side storage technology *cd* in sector *d* [USD/kWh], ***PF$_p$***: Fuel cost for power generation technology *p* [USD/kWh], ***CTAX***: Carbon cost [USD/tCO_2], ***Carbon$_p$***: Carbon emissions of power generation technology *p* [tCO_2/GWh], ***VC$_{d,v,s,t}$***: Cost in sector *d*, in season *s*, at time *t*, at electricity saved *v* [USD/kWh], ***LDC$_{d,s,t}$***: Sectoral electric power load [GW], ***HW$_{s,t}$***: Time slot length in season *s*, at time *t* [hours], ***LGM$_s$***: Length of each season (assumed as summer 3 months, winter 3 months, intermediate season 6 months) [months], ***LGT$_t$***: Length of each time zone (1 hour)[hours]

(2) Constraint on the electricity supply and demand balance

Eq. 4-8 shows the supply-demand balance of the whole power system while Eq. 4-9 and Eq. 4-10 show that of each demand sector. The first term on the left side of Eq. 4-8 represents the output of power generation technologies (except for residential PV), the second term represents the supply from residential PV to the system, and the third term, the net discharge of supply-side storage. The right side represents the sum of *nld* (considering the transmission/distribution loss). *nld* is defined as the sectoral load *LDC* minus the supply from residential PV, the net discharge from demand-side storage on the demand side, and the amount of electricity saving (Eq. 4-9, Eq. 4-10).

$$\sum_{p=1}^{9} xp_{p,s,t} + dtg_{s,t} + \sum_{c}(xo_{c,s,t} - xi_{c,s,t}) = \sum_{d} nld_{d,s,t}/(1 - LOS) \qquad \text{Eq. 4-8}$$

$$nld_{1,s,t} + dtd_{s,t} + \sum_{cd}(xod_{1,cd,s,t} - xid_{1,cd,s,t}) = LDC_{1,s,t} \cdot \left(1 - \sum_{v} xv_{1,v,s,t}\right) \qquad \text{Eq. 4-9}$$

$$\sum_{d} nld_{d,s,t} + \sum_{cd}(xod_{d,cd,s,t} - xid_{d,cd,s,t}) = LDC_{d,s,t} \cdot \left(1 - \sum_{v} xv_{d,v,s,t}\right) \; (d = 2, 3) \qquad \text{Eq. 4-10}$$

LOS: Transmission/distribution loss rate (assumed to be 5%).

(3) Constraint on the installed capacity

Eq. 4-11 to Eq. 4-13 constrain the upper and lower limits of capacity of power generation and storage technologies. The lower limit corresponds to the initial value (input value) of the simulation. We set upper limits considering policy direction, power development trends and so on (Section 4-3-2).

$$KPD_p \le kp_p \le KPU_p \qquad \text{Eq. 4-11}$$

$$KCD_c \le kc_c \le KCU_c \qquad \text{Eq. 4-12}$$

$$KCDD_{d,cd} \le kcd_{d,cd} \le KCDU_{d,cd} \qquad \text{Eq. 4-13}$$

KPD$_p$: Initial capacity of power generation technology *p* [GW], ***KPU$_p$***: Maximum installed capacity of power generation technology *p* [GW], ***KCD$_c$***: Initial capacity of supply-side storage technology *c* [GW], ***KCU$_c$***: Maximum installed capacity of supply-side storage technology *c* [GW], ***KCDD$_{d,cd}$***: Initial installed capacity of demand-side storage technology *cd* in sector *d* [GW], $\boldsymbol{KCDU_{cd}}$: Maximum installed capacity of demand-side storage technology *cd* in sector *d* [GW].

(4) Constraint on the power generation output

The output of each power generation technology is limited to be less than operational capacity. Eq. 4-14 constrains the output of power generation technologies except wind power, supply-side PV, and residential PV. Eq. 4-15 constrains the output of wind power and supply-side PV. These power generation output profiles *SU* are given exogenously, and their power generation output is supplied to the power grid (*xp*) or suppressed (*de*). Eq. 4-16 is about the output of residential PV. As with Eq. 4-15, the power generation output profile is given exogenously, and the power generation output is consumed at residential sector (*dtd*), supplied to the grid (*dtg*), or suppressed (*ded*).

$$xp_{p,s,t} \le PAV_{p,s} \cdot kp_p \; (p = 1, \dots, 7) \qquad \text{Eq. 4-14}$$

$$xp_{p,s,t} + de_{p,s,t} = SU_{p,s,t} \cdot kp_p \; (p = 8, 9) \qquad \text{Eq. 4-15}$$

$$xp_{10,s,t} + ded_{s,t} = SUD_{s,t} \cdot kp_{10} \qquad \text{Eq. 4-16}$$

$$xp_{10,s,t} = dtd_{s,t} + dtg_{s,t} \qquad \text{Eq. 4-17}$$

$\boldsymbol{PAV_p}$: Availability of power generation technology *p*, $\boldsymbol{SU_{p,s,t}}$: Output profile of wind and supply-side PV (*p* = 8, 9), $\boldsymbol{SUD_{s,t}}$: Output profile of demand-side PV.

(5) Constraint on the ramping capability (for thermal generation plants)

Eq. 4-18 to Eq. 4-21 constrain the ramping capability of nuclear and fossil fuel-fired plants. This study assumes that the ramping capability relies on the installed capacity.

$$xp_{p,s,t} \le xp_{p,s,t-1} + kp_p \cdot RU_p \; (p = 1, \dots, 5, t \ne 0) \qquad \text{Eq. 4-18}$$

$$xp_{p,s,t} \ge xp_{p,s,t-1} - kp_p \cdot RD_p \; (p = 1, \dots, 5, t \ne 0) \qquad \text{Eq. 4-19}$$

$$xp_{p,s,0} \le xp_{p,s,23} + kp_p \cdot RU_p \; (p = 1, \dots, 5) \qquad \text{Eq. 4-20}$$

$$xp_{p,s,0} \ge xp_{p,s,23} - kp_p \cdot RD_p \; (p = 1, \dots, 5) \qquad \text{Eq. 4-21}$$

$\boldsymbol{RU_p}$: Maximum ramp-up rate of power generation technology *p*, $\boldsymbol{RD_p}$: Maximum ramp-down rate of power generation technology *p*.

(6) Constraint on the minimum output (for thermal plants)

The minimum output level of thermal power generation is calculated by subtracting the capacity of DSS (daily start and stop) mode plants (rate *DSS*) from the maximum daily output and by multiplying minimum output rate (*PMIN*). The thermal power generation technologies capable of DSS operation are LNG thermal, CCGT and oil-fired power generation in this study.

$$xp_{p,s,t} \ge PMIN_p \cdot (mp_{p,s} - DSS_p \cdot PAV_{p,s} \cdot kp_p) \; (p = 1, \dots, 5) \qquad \text{Eq. 4-22}$$

$$mp_{p,s} \ge xp_{p,s,t} \; (p = 2, \dots, 5) \qquad \text{Eq. 4-23}$$

$\boldsymbol{PMIN_p}$: Minimum output rate of power generation technology *p*, $\boldsymbol{DSS_p}$: Share of DSS (daily start and stop) operation of power generation technology *p*.

(7) Constraint of power storage

The constraints on the amount of charge/discharge of power storage technologies are represented by Eq. 4-24 to Eq. 4-31. Constraints on the charge/discharge capacity of power storage technologies [kW] are expressed by Eq. 4-24 and Eq. 4-25. Stored electricity [kWh] is expressed by Eq. 4-26 to Eq. 4-29. The loss of power storage is considered as the self-discharge rate (*SL*) and the charge/discharge efficiency (*CL*). Constraints on the storage capacity of power storage technologies [kW] are expressed by Eq. 4-30 and Eq. 4-31. This study defines the storage capacity (*CRT* or *CDRT*) per installed capacity of power storage technologies and restricts it to the value multiplied by the charge/discharge capacity (*kc* or *kcd*) or less.

$$xo_{c,s,t} + xi_{c,s,t} \leq CAV_c \cdot kc_c \quad \text{Eq. 4-24}$$

$$xod_{d,cd,s,t} + xid_{d,cd,s,t} \leq CDAV_{d,cd} \cdot kcd_{d,cd} \quad \text{Eq. 4-25}$$

$$sc_{c,s,t} = sc_{c,s,t-1} \cdot (1 - SL_c) + (xi_{c,s,t} \cdot \sqrt{CL_c} - xo_{c,s,t}/\sqrt{CL_c}) \cdot HW_{s,t}\ (t \neq 0) \quad \text{Eq. 4-26}$$

$$sc_{c,s,0} = sc_{c,s,23} \cdot (1 - SL_c) + (xi_{c,s,0} \cdot \sqrt{CL_c} - xo_{c,s,0}/\sqrt{CL_c}) \cdot HW_{s,t} \quad \text{Eq. 4-27}$$

$$scd_{d,cd,s,t} = scd_{d,cd,s,t-1} \cdot (1 - SDL_{cd}) + (xid_{d,cd,s,t} \cdot \sqrt{CDL_{cd}} - xod_{d,cd,s,t}/\sqrt{CDL_{cd}}) \cdot HW_{s,t}\ (t \neq 0) \quad \text{Eq. 4-28}$$

$$scd_{d,cd,s,0} = scd_{d,cd,s,23} \cdot (1 - SDL_{cd}) + (xid_{d,cd,s,0} \cdot \sqrt{CDL_{cd}} - xod_{d,cd,s,0}/\sqrt{CDL_{cd}}) \cdot HW_{s,t} \quad \text{Eq. 4-29}$$

$$sc_{c,s,t} \leq CRT_c \cdot CAV_{c,s,t} \cdot kc_c \quad \text{Eq. 4-30}$$

$$scd_{d,cd,s,t} \leq CDRT_{d,cd} \cdot CDAV_{cd,s,t} \cdot kcd_{d,cd} \quad \text{Eq. 4-31}$$

CAV_c: Availability of supply-side storage technology *c*, $CDAV_{d,cd}$: Availability of demand-side storage technology *cd* in sector *d*, SL_c: Self-discharge rate of supply-side storage technology *c*, CL_c: Charge/discharge loss rate of supply-side storage technology *c*, SDL_{cd}: Self-discharge rate of demand-side storage technology *cd*, CDL_{cd}: Charge/discharge loss rate of demand-side storage technology *cd*, CRT_c: Storage capacity per installed capacity of supply-side storage technology *c*, $CDRT_{cd}$: Storage capacity per installed capacity of demand-side storage technology *cd*.

(8) Constraint on the capacity reserve

A certain level of reserve margin (*RSM*) is required for a power system to maintain stable power supply. This study assumes a reserve margin of 8% (*RSM* = 8%).

$$\sum_{p=1}^{7} PAV_{p,s,t} \cdot kp_p + \sum_{c} CAV_{c,s,t} \cdot kc_c \geq (1 + RSM) \cdot \sum_{d} nld_{d,s,t} \qquad \text{Eq. 4-32}$$

RSM: Reserve margin (assumed to be 8%)

(9) Modeling of the cost for electricity saving

This study follows the modeling approach presented in Fujii and Yamaji (1995). We estimated the loss of consumer utility due to electricity saving based on the short-run price elasticity of power demand. The price elasticity of demand represents the percentage of change in demand when the price of electricity changes by 1%. Assuming the short-run price elasticity β in sector d, at every time t, it is represented as Eq. 4-33.

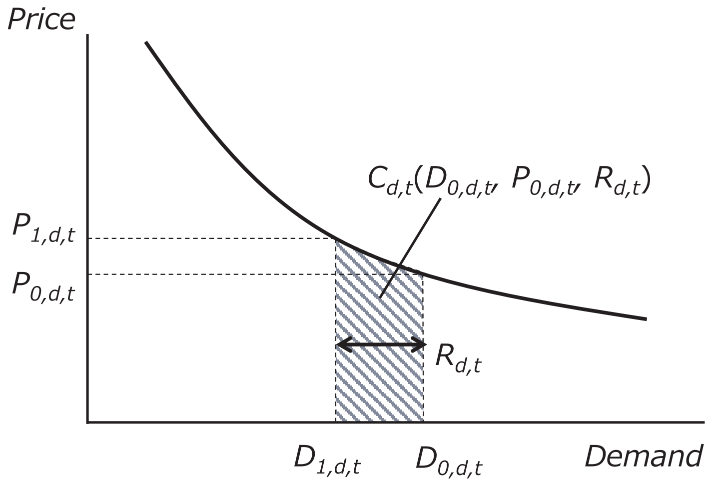
$$-\beta_{d,t} = \frac{dD_{d,t}/D_{d,t}}{dP_{d,t}/P_{d,t}} \qquad \text{Eq. 4-33}$$

From the definition of the short-run price elasticity (Eq. 4-33), the relationship between $D_{d,t}$ and $P_{d,t}$ is represented as follows in a neighborhood of $D_{0,d,t}$ and $P_{0,d,t}$, which are the reference demand and reference energy price at time t, respectively.

$$P_{d,t}(D_{d,t}) = P_{0,d,t}\left(D_{d,t}/D_{0,d,t}\right)^{-1/\beta_{d,t}} \qquad \text{Eq. 4-34}$$

This is a demand curve drawn as shown in Figure 4-2. Here, electricity saving $R_{d,t}$ is calculated from the reference demand $D_{0,d,t}$ minus $D_{1,d,t}$ ($D_{1,d,t} < D_{0,d,t}$). Then, the utility decreases by the hatched area compared with when the demand is $D_{0,d,t}$. This is considered as the cost of the electricity saving at time t.

Figure 4-2 Illustration of loss of consumer utility due to electricity saving



Source: Prepared by APERC referring to Fujii and Yamaji (1995)

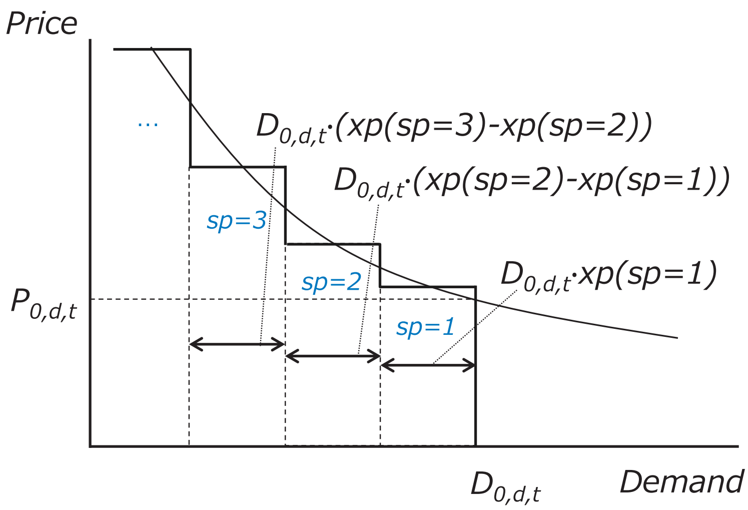
The electricity saving cost $C_{d,t}$ ($D_{0,d,t}$, $P_{0,d,t}$, $R_{d,t}$) is represented as follows, where the amount of electricity saving in sector d, at time t, is represented as $R_{d,t}$ (= $D_{0,d,t} - D_{1,d,t}$).

$$C_{d,t}(D_{0,d,t}, P_{0,d,t}, R_{d,t}) = \int_{D_{1,d,t}}^{D_{0,d,t}} P_{d,t}(D_{d,t})dD_{d,t}$$
$$= \int_{0}^{R_{d,t}} P_{0,d,t}\left(\frac{D_{0,d,t}-R_{d,t}}{D_{0,d,t}}\right)^{-1/\beta_{d,t}} dR_{d,t}$$
$$= \begin{cases} \dfrac{\beta_{d,t}}{1-\beta_{d,t}} D_{0,d,t}P_{0,d,t}\left\{\left(\dfrac{D_{0,d,t}-R_{d,t}}{D_{0,d,t}}\right)^{\frac{\beta_{d,t}-1}{\beta_{d,t}}} - 1\right\} & (\beta_{d,t} \neq 1) \\ D_{0,d,t}P_{0,d,t}\log\left(\dfrac{D_{0,d,t}}{D_{0,d,t}-R_{d,t}}\right) & (\beta_{d,t} = 1) \end{cases} \quad \text{Eq. 4-35}$$

We added Eq. 4-35 to the objective function. Electricity saving $R_{d,t}$ is endogenously determined through optimization. Eq. 4-36 describes the cost per unit amount of electricity saving. To incorporate the non-linear demand curve into linear programming model, we approximated the demand curve, using step function as illustrated in Figure 4-3.

$$c_t(D_{0,d,t}, P_{0,d,t}, R_{d,t}) = \frac{C(D_{0,d,t}, P_{0,d,t}, R_{d,t})}{R_{d,t}} \quad \text{Eq. 4-36}$$

Figure 4-3 Illustration of step approximation of the demand function



Source: Prepared by APERC referring to Fujii and Yamaji (1995)

We can arbitrarily decide the step width and maximum saving potential. This study assumes the maximum saving of up to 20% from the reference demand at each time, and the step width of electricity saving as 2% (in other words, we assume that the unit electricity saving cost changes by 2% steps). In this case, the electricity saving step is as represented by Eq. 4-37, and the unit cost of each electricity saving step $c'_{d,t}$ ($D_{0,d,t}$, $P_{0,d,t}$, sp) is as represented by Eq. 4-38.

$$x(sp) = 0.02 \cdot sp \quad (sp = 0, 1, \dots, 10) \qquad \text{Eq. 4-37}$$

$$c'_{d,t}(D_{0,d,t}, P_{0,d,t}, sp) = \frac{C(D_{0,d,t}, P_{0,d,t}, x(sp)) - C(D_{0,d,t}, P_{0,d,t}, x(sp-1))}{(x(sp) - x(sp-1)) \cdot D_{0,d,t}} \qquad \text{Eq. 4-38}$$

Eq. 4-39 shows the total electricity saving cost of all sectors, and Eq. 4-40 defines the step width. Electricity saving is calculated by optimization of the endogenous variable XS.

$$\sum_{d}\sum_{t}\sum_{sp} c'_{d,t}(D_{0,d,t}, P_{0,d,t}, sp) \cdot D_{0,d,t} \cdot XS_{sp,d,t} \qquad \text{Eq. 4-39}$$

$$XS_{sp,s,t} \le x(sp) - x(sp-1) \qquad \text{Eq. 4-40}$$

This study set the short-run price elasticity $\beta_{d,t}$ by sector, and assumes that it is constant regardless of the time (Section 4-4). The reference demand $D_{0,d,t}$ is $LDC_{d,s,t}$. The same reference price $P_{0,d,t}$ is use among sectors. We obtain the price from the marginal power generation cost (the shadow price of Eq. 4-9 or Eq. 4-10) in the "no electricity saving" case described in Section 4-4. Eq. 4-39 corresponds to Eq. 4-6, and XS_{sp} in Eq. 4-39 and Eq. 4-40 corresponds to the endogenous variable $xv_{d,v,s,t}$.

4-3-2 Input data

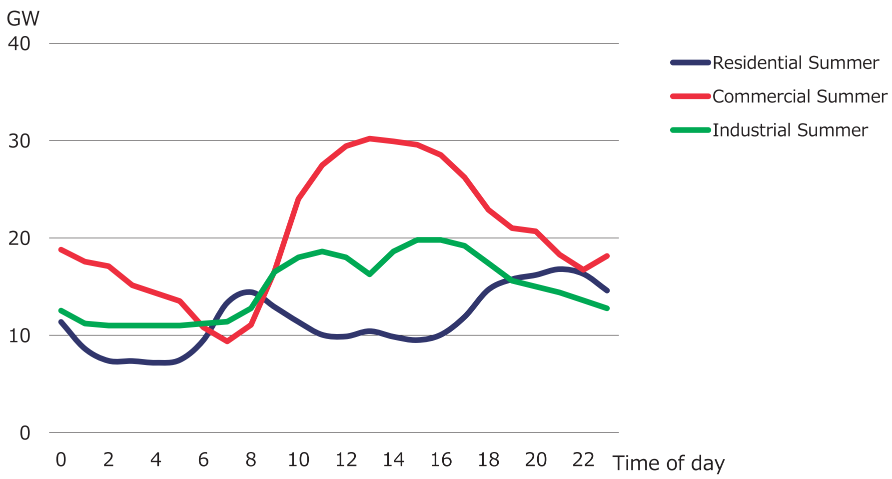
This section provides an outline of the data input into the model. This study simulates the Kanto region of Japan. We set the assumptions in a consistent way, comparing multiple sources from the Japanese government, electric utilities, and scholarly papers. The simulation cases in this study are described in Section 4-4.

(1) Power demand and daily load curves

The annual power demand is assumed to be 317 TWh based on the historical data in the Tokyo Electric Power Company service area in 2010 (TEPCO, 2015). The sectoral load pattern is obtained from the estimation by The Institute of Energy Economics, Japan (IEEJ). Figure 4-4 shows examples in summer. IEEJ estimated them using a bottom-up approach, considering the usage patterns of home appliances, power/heat load patterns by industry, cooling/heating demand patterns by season and sector, etc. We confirmed that the synthetic demand is almost consistent with the actual data.

Each sector shows its load characteristics (Figure 4-4). In the residential sector, the load increases around 8 a.m. and from 6 p.m. to midnight. The former is the time from waking up to leaving home for school or work, and the latter is the time from coming back home to going to bed. Power consumption increases in these time zones for lighting, air conditioning, cooking, TV watching and other information- or entertainment-related activities. On the other hand, in the commercial and industrial sectors, the load curves show a mountain shape during business hours. The load increases greatly especially in the commercial sector, mainly because the air conditioning demand increases with temperature change. In Kanto region, commercial sector has relatively large impacts on the shape of the synthetic load curve.

Figure 4-4 Sectoral daily load curve (example in summer)



Source: Estimated by the Institute of Energy Economics, Japan

(2) Power generation/power technology related data

Table 4-2 and Table 4-3 show the assumptions for power generation. We referred to the governmental estimation and existing research papers: METI (2015a) for the construction cost, design life, power generation efficiency, and own consumption rate, and Komiyama, et al. (2015) for the ramping capability of nuclear and thermal power generation, DSS operation rate and minimum output constraint. The fuel cost for nuclear power generation is determined from METI (2015a), and the fossil fuel cost is the historical data in 2013 from EDMC (2015). The installed capacity of photovoltaic and wind power generation is estimated from METI (2015b), and other data is from TEPCO (2015). This model estimates the annualized construction cost by multiplying the construction costs and the capital recovery factor. Assumed interest rate is 3%.

Table 4-2 Assumption of nuclear and thermal power generation

	Nuclear	Coal	Gas ST	CCGT	Oil
Construction cost [USD/kW]	4083	2376	1140	1140	1900
Life time [years]	40	40	40	40	40
Annual O&M cost rate [%]	4.1	3.3	2.3	2.3	2.7
Maximum capacity [GW]	13.5	6.6	13.5	17.0	12.9
Existing capacity [GW]	13.5	6.6	13.5	17.0	12.9
Maximum ramp-up rate [%]	0	31	82	82	1
Maximum ramp-down rate [%]	0	58	75	75	1
Share of daily start and stop [%]	0	0	30	50	70
Minimum output level [%]	30	30	20	20	30
Maximum availability [%]	56	75	65	65	80
Efficiency [%]	100	42	40	52	39
Own consumption rate [%]	4.0	6.4	4.0	2.0	4.8
Fuel cost [USD/specific unit]	0.146	0.075	0.43	0.43	0.47
Heat content [kcal/specific unit]	860	6213	13160	13160	9126
Carbon content [kg-C/specific unit]	0	0.62	0.75	0.75	0.79
Specific unit	kWh	kg	kg	kg	l

Source: METI (2015a); Komiyama, et al. (2015); TEPCO (2015) and EDMC (2015)

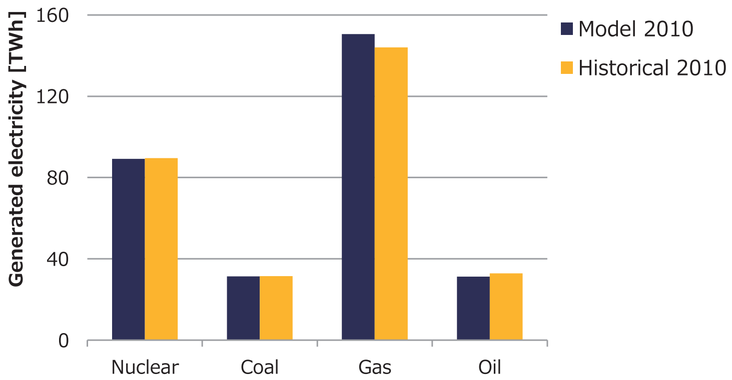
Table 4-3 Assumption of power generation from renewable energy

	Hydro	Geothermal	Wind	Supply-side PV	Residential PV
Construction cost [USD/kW]	6081	7507	2699	2794	3459
Life time [years]	60	50	20	20	20
Annual O&M cost rate [%]	1.0	4.0	2.0	1.0	1.0
Maximum capacity [GW]	6.8	0.0	0.2	5.4	2.4
Existing capacity [GW]	6.8	0.0	0.2	5.4	2.4

Source: METI (2015a); Komiyama, et al. (2015); TEPCO (2015) and METI (2015b)

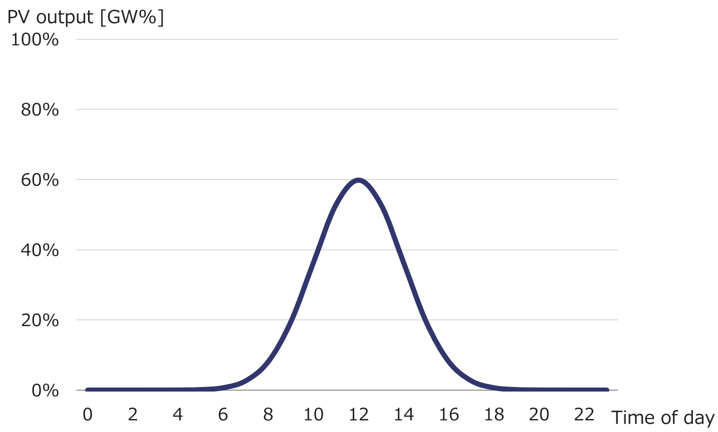
In considering the maximum availability for nuclear, thermal and hydro power generation, we estimated the values using historical capacity and generation data in FY2010. We confirmed that the model reproduce the results similar to the actual power system in FY2010, by applying the historical demand and installed capacity in FY2010 (Figure 4-5). For wind and PV (*SU* and *SUD* in Eq. 4-15 and Eq. 4-16), this preliminary study relies on simple assumptions. The output profile for wind is assumed to be 20% for all seasons at all time. As for supply-side and residential PV, the assumed output profile for all season is shown in Figure 4-6 (with a capacity factor of 12%). This study does not consider short-term and seasonal output variability; detailed discussion is important in the future work.

Figure 4-5 Comparison of modeled generated electricity and historical data in FY2010 in Kanto region of Japan



Source: APERC analysis

Figure 4-6 Assumed output profile of supply-side and residential PV for all seasons



Source: APERC analysis

The cost of the storage technologies is obtained mainly from Komiyama, et al. (2015) (Table 4-4). Batteries are assumed to be lithium ion batteries. This study does not assume the new construction of pumped hydro storage; only batteries can be additionally installed.

Table 4-4 Assumption of power storage technologies

	Pumped hydro	Batteries (for both the supply side and demand side)
Construction cost [USD/kW]	2480	1000
Life time [years]	60	10
Annual O&M cost rate [%]	1.0	1.0
Non-durable material cost [USD/kWh]	0	800
Life cycle [time]	∞	3500
Maximum capacity [GW]	8.7	∞
Existing capacity [GW]	8.7	0
Cycle efficiency [%]	70	95
Self-discharge loss [%/hour]	0.01	0.1
kWh capacity ratio	0.13	2
Maximum availability [%]	0.9	0.9

Source: Komiyama, et al. (2015)

(3) Other data (carbon cost, reference price of the electricity saving cost and price elasticity)

The carbon cost is determined to be 30 USD/tCO_2. For the reference price of the electricity saving cost, this study uses the marginal power generation cost for each time zone, which is obtained in the "base case (no electricity saving case)" in the next section. Assumptions for the price elasticity of demand are also discussed in the next section.

4-4 Case Settings, Results and Discussion

This section performs two analyses as a trial of the model. The first is about the price elasticity and electricity saving effect in the residential and commercial sectors, and the second is about the role of electricity saving for massive integration of PV.

4-4-1 Analysis on Price Elasticity of Residential and Commercial Sectors

Various studies have estimated the short-run price elasticity of power demand in Japan, especially for the industrial and residential sectors. The range of estimated elasticity is relatively narrow in industry, while it shows wide range in residential sector (see the next paragraph). As for commercial sector, to our knowledge, only a few studies have discussed its elasticity. This section focuses on the residential sector for which estimates provided by existing studies vary widely, as well as the commercial sector for which there are a relatively small number of estimates. We discuss the effect of their elasticity on the whole electricity system.

Existing studies have estimated price elasticity in Japan mainly using statistics or data obtained from experimental projects. For industrial sector, the estimated values, using historical data, range from 0.1 to 0.3 (Akiyama & Hosoe, 2008; Osanai & Saito, 2011; Murakami, 2012). For the residential sector, estimates vary widely from 0.056 to 0.92 depending on the literature (Tanishita, 2009; Mizobata, et al., 2011; Murakami, 2012). Regarding the commercial sector, there are fewer estimates using actual results compared to the residential and industrial sectors. Smart community experimental projects were conducted at four places in Japan (JSCP, 2015) after 2010, and several estimates use the results. For instance, Keihanna Science City, which mainly handles the residential and commercial sectors,[5] reports values of 0.1 to 0.2, while the projects in Kitakyushu City[6] estimates the value at approximately 0.1 (Ida, et al., 2013).

We set the simulation cases based on these estimates (Table 4-5). The price elasticity is fixed at 0.2 for industry sector, whose values are relatively constant in existing estimates. For residential and commercial sectors, we assume six cases as shown in Table 4-5. The reference price ($P_{0,d,t}$ in Section 4-2-1) is assumed to be constant across all sectors and time zones; we use the weighted seasonal average of marginal power generation cost in the "no electricity saving" case as the reference price. This assumes the situation where the pricing system changes from average cost basis to real-time cost basis. Electricity saving is selected based on economic rationality, by comparing real-time cost and marginal cost of saving. Other price mechanisms such as critical peak price (CPP) are not considered here.

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[5] The number of families subject to verification was 14 for the introduction of HEMS, approx. 100 for the introduction of visualization of energy, and approx. 700 for the power demand response (DR), as of April 2012. The number of offices subject to verification was one (Keihanna Plaza).

[6] The number of families and offices subject to verification was 225 and 50, respectively, as of August 2012.

Table 4-5 Case setting: Sensitivity analysis on the short-run price elasticity of the residential and commercial sectors

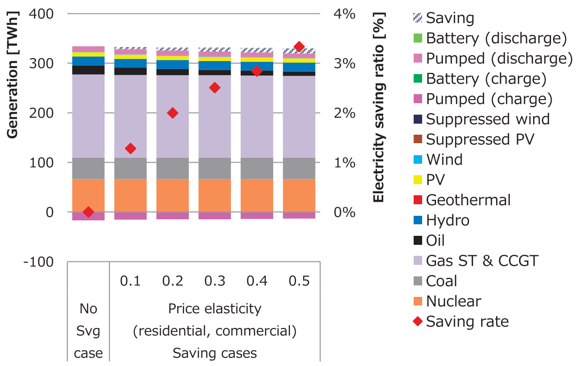
Short-run price elasticity of the residential and commercial sectors	No electricity saving (*NoSvg* case), 0.1, 0.2, 0.3, 0.4, 0.5
Short-run price elasticity of the industrial sector	0.2

Source: APERC analysis

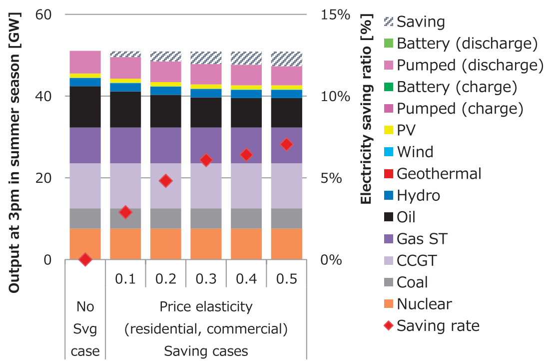
Electricity savings would bring a certain level of peak cutting effect, although its effect on the annual power generation is modest. Electricity saving accounts only for 1% to 2% in annual power generation with the price elasticity estimated above-mentioned experimental projects (approx. 0.1 to 0.2), and no more than approximately 3% even when assuming a higher elasticity (0.3 to 0.4) (Figure 4-7a). In contrast, the results also imply a certain peak-cut effect even with a lower elasticity. For instance, as shown in Figure 4-7b, peak-cut effect reaches about 5% with a price elasticity of 0.2, and it increases to approximately 7% (4 GW) with an elasticity of 0.5.

Figure 4-7 Annual power generation and the power generation output in the cross section at the peak time in summer (3 p.m.)

a) Annual power generation



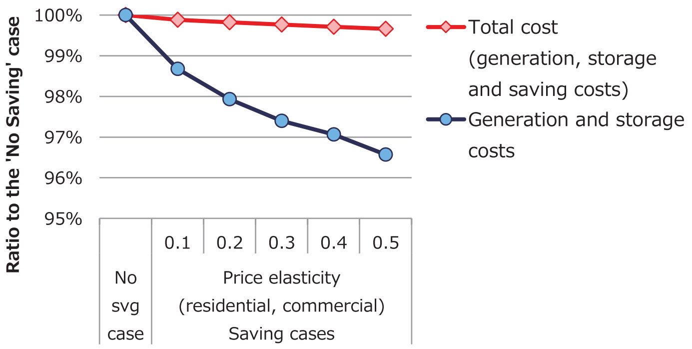
b) Power supply in the cross section at the peak time in summer (3 p.m.)



Source: APERC analysis
(Note) Gas ST: Gas thermal; CCGT: Combined cycle gas turbine

The total cost, including the electricity saving cost, decreases slightly in all cases compared with the no electricity saving case (Figure 4-8). Although the cost on the supply side (power generation and power storage costs) is more greatly reduced, the reduction is no more than approximately 3.4% with a price elasticity of 0.5, and 1.3% to 2.1% with a price elasticity of 0.1 to 0.2. As shown in Figure 4-7 (b), the peak-cut effect reduces peak load generation (such as oil-fired), lowering the variable costs for these plants. In the case where the elasticity is 0.5, the variable cost for oil-fired generation decreases by approximately 116 billion yen annually compared with the no electricity saving case. However, as the electricity saving is limited expect in the peak time zone, the cost reductions would have modest effects on annual generation and storage costs (around four trillion yen). It should be noted that this study only discusses short-term cost benefits, and therefore long-term costs and benefits including the capital investment reduction effect are not considered. It is necessary to make the models dynamic and discuss the long-term effects as well in the future research.

Figure 4-8 Total cost and change in power generation and storage costs



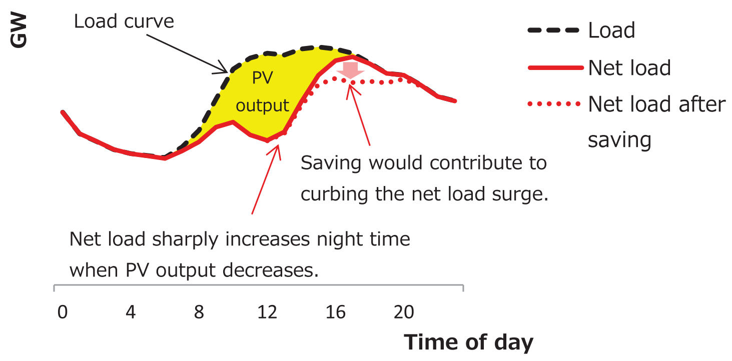
Source: APERC analysis

4-4-2 Analysis on the Role of Electricity Saving for Massive PV Integration

In the United States, where a load peak occurs in the evening, a “duck curve problem” occurs with the large-scale installation of PV system (NEDO, 2015). The duck curve problem is where the net load in the daytime decreases significantly due to the output surge of PV system, resulting in a steep net load curve to the peak time, and therefore a large-scale back-up is promptly required in the evening. In many regions in Japan,[7] the load curve is a mountain shape with a peak in the daytime, which would be relatively compatible with PV generation. However, massive PV installation would result in a large net load difference between the daytime and nighttime, causing a duck curve problem in Japan as well (Figure 4-9). If electricity saving is conducted in the evening by demand response, it is expected to reduce the net load peak, and therefore mitigate the duck curve problem. This section discusses the role of electricity saving for ensuring the demand and supply balance under massive PV installation.

[7] Kanto and Kansai regions, for example. In Hokkaido, however, a peak is likely to occur in the evening.

Figure 4-9 Illustration of a duck curve and the role of electricity saving



Source: APERC analysis

Table 4-6 shows the case settings. We simulated total ten cases, with five types of PV capacity (exogenous variable) and two types of electricity saving assumptions (No saving case and saving case). This study first run the five cases without electricity saving, and estimated the reference price ($P_{0,d,t}$ in Section 4-2-1). Then, we simulated the five cases with electricity saving. The assumed PV capacity is based on the ratio to the peak load. The PV capacity equivalent to the peak load (="100%" case) is 49GW in this section. The share between supply-side and residential PV is fixed to the current share (Table 4-3). The price elasticity of demand is assumed to be 0.2 for all sectors.

Table 4-6 Case setting: Analysis of the amount of electricity saving when photovoltaic power generation is introduced on a large scale

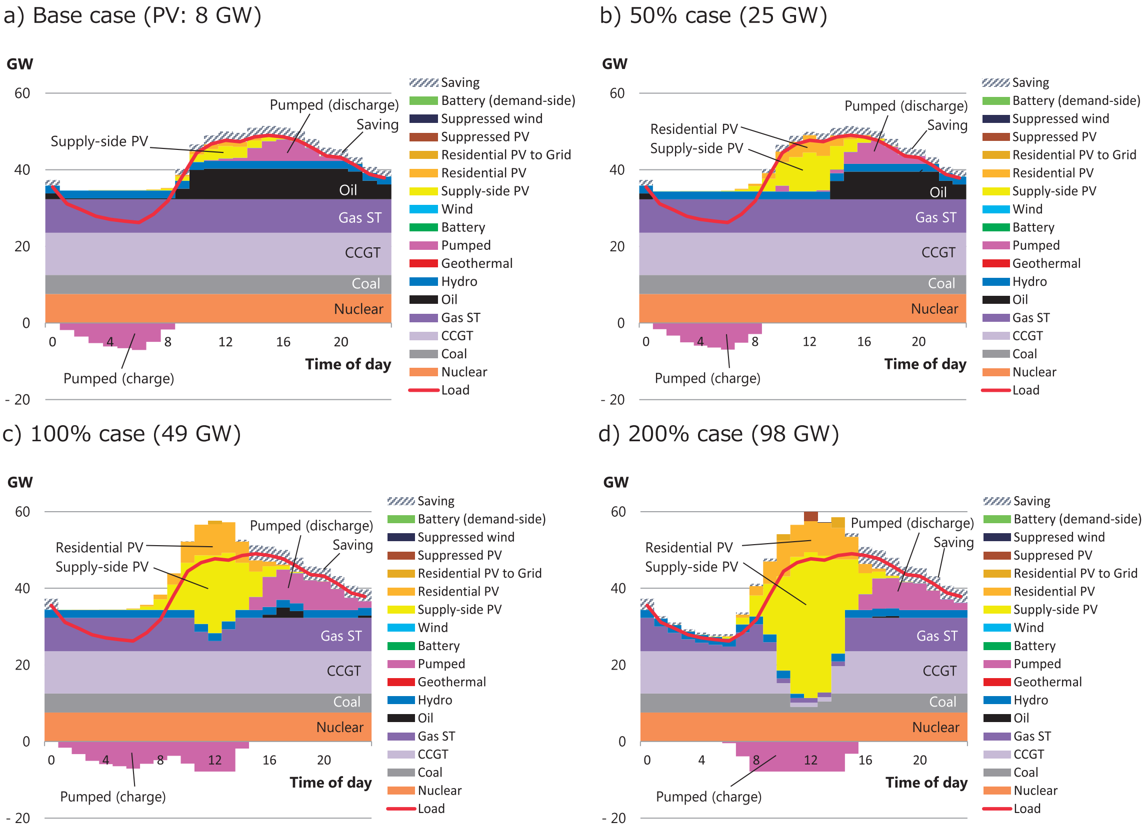
Installed capacity of PV	Current level (base case), 50%, 100%, 150%, 200% (numbers indicate the ratio to peak load level)
Electricity saving	No saving case, Saving case

Source: APERC analysis

Figure 4-10 shows the power generation profile in summer season with electricity saving. In the Base case, electricity is saved from around 9 a.m. with the demand increase to the evening, and the "50%" case also shows similar trends. In both cases, electricity saving reaches the maximum at the peak time in summer (3 p.m.) (Figure 4-11, approx. 2.5 GW and 2 GW, respectively). By contrast, the timing of electricity saving shifts to nighttime under the massive installation cases (for example, "100%" and "200%" cases). Electricity saving is not conducted during the daytime when a part of PV output become surplus electricity, but rather conducted from the afternoon to nighttime when the PV output decreases, contributing to curbing the net load peak in the evening. (Figure 4-10(c)-(d) and Figure 4-11).

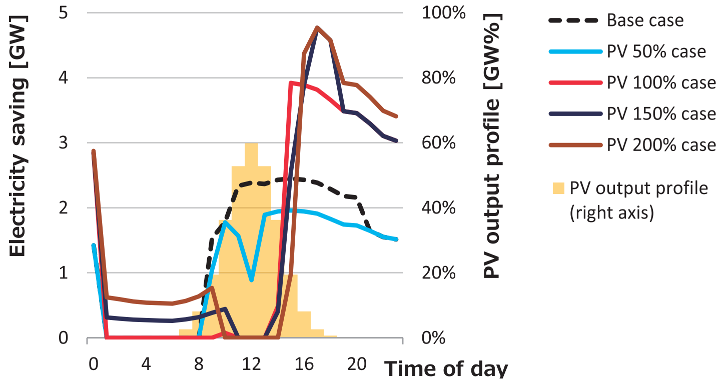
Our results also suggest that it would be important to dynamically combine supply-side and demand-side measures to integrate renewable cost-effectively. As mentioned above, electricity saving in the demand-side contributes to curbing the net load peak, but Figure 4-10 also shows that supply-side integration measures, such as ramping operation of flexible generation and electricity storage by pumped hydro, play a significant role to absorb the diurnal PV variability during the day. For instance, gas-fired and coal-fired generation reduce their output, and pumped hydro charges surplus electricity during the daytime when the PV output surges as depicted in Figure 4-10(d). These technologies also contribute to ensuring the supply-demand balance at the net load peak time in the evening. Discussion on a smart grid tends to focus on the measures on the demand side; however, from the viewpoint of the integration of variable renewable energy, it would be important for the demand side and supply side to cooperate to appropriately combine various measures in the both sides.

Figure 4-10 Power generation profile in summer with electricity saving case



Source: APERC analysis

Figure 4-11 Amount of electricity saving in each case (in summer)



Source: APERC analysis

4-5 Chapter Conclusion and Future Challenges

This section developed an optimal power generation mix model of the Kanto region of Japan considering electricity saving, and performed analyses of the price elasticity of demand as well as of the role of electricity saving for massive PV integration. The former analysis shows that electricity savings would bring a certain level of peak cutting effect, although its effect on the annual power generation is modest (Figure 4-7). The latter analysis implies that, under the massive PV installation, electricity saving contributes to curbing the net load peak in the evening (Figure 4-10 and Figure 4-11). The latter analysis also implies that, from the systems viewpoints, it would be important to dynamically combine both demand-side and supply-side measures to integrate massive PV cost-effectively (Figure 4-10).

However, it should be noted that these analyses are based on simple assumptions, and there is still room for improvements in several aspects. The three major future research topics are as follows. First, demand shift needs to be modeled in a more detailed manner. The current model only considers electricity storage facilities. Other demand shift measures, including the time shift of electric appliances use, would allow a more comprehensive analysis about demand response. Second topic is about the improvement of temporal resolution of the model. Future work needs to increase the number of time slices to explicitly consider seasonal and short-term variability in the model. Third, future work need to consider dynamic analyses. This study does not consider longer-term benefits, such as the investment saving effects thanks to demand response. It would be necessary to make the model dynamic in order to quantitatively and comprehensively discuss the costs and benefits of smart community concepts.

Chapter 5　Conclusion

This study compiled the cost and benefit elements of a smart community in order to develop evaluation methods for smart communities. The study developed a power generation mix model for the power generation sector considering electricity saving, conducted sensitivity analysis in relation to the price elasticity on the demand side, and analyzed the amount of electricity saving at the time when photovoltaic power generation is introduced.

Planning of smart communities and evaluation of the effects are likely to focus only on efforts made on the demand side, but this study showed that there was a close relationship with the power generation mix, and it was necessary to evaluate the social system as a whole. This study also revealed that the costs and benefits of a smart community depended on the stakeholders in addition to the stage of development of the power infrastructure, the region, such as an urban area, rural area, and island, and the purpose of investment, and therefore evaluation focusing on specific targets was required when determining the policy for the diffusion of a smart community.

The analysis with the power generation mix model showed that electricity savings would bring a certain level of peak cutting effect, although its effect on the annual power generation is modest. Our results also imply that, under the massive PV installation, electricity saving contributes to curbing the net load peak in the evening. Also, it would be important to dynamically combine both demand-side and supply-side measures to integrate massive PV cost-effectively.

Turning to the future work, it is necessary to construct a comprehensive framework that converts the cost and benefit elements, extracted in this study, into monetary values to quantitatively evaluate the social system as a whole. As for the power generation mix model, future work needs to model the demand shift measures in a more detailed manner, improve the temporal resolution of the model, and make the model dynamic to comprehensively discuss the costs and benefits of smart community concepts.

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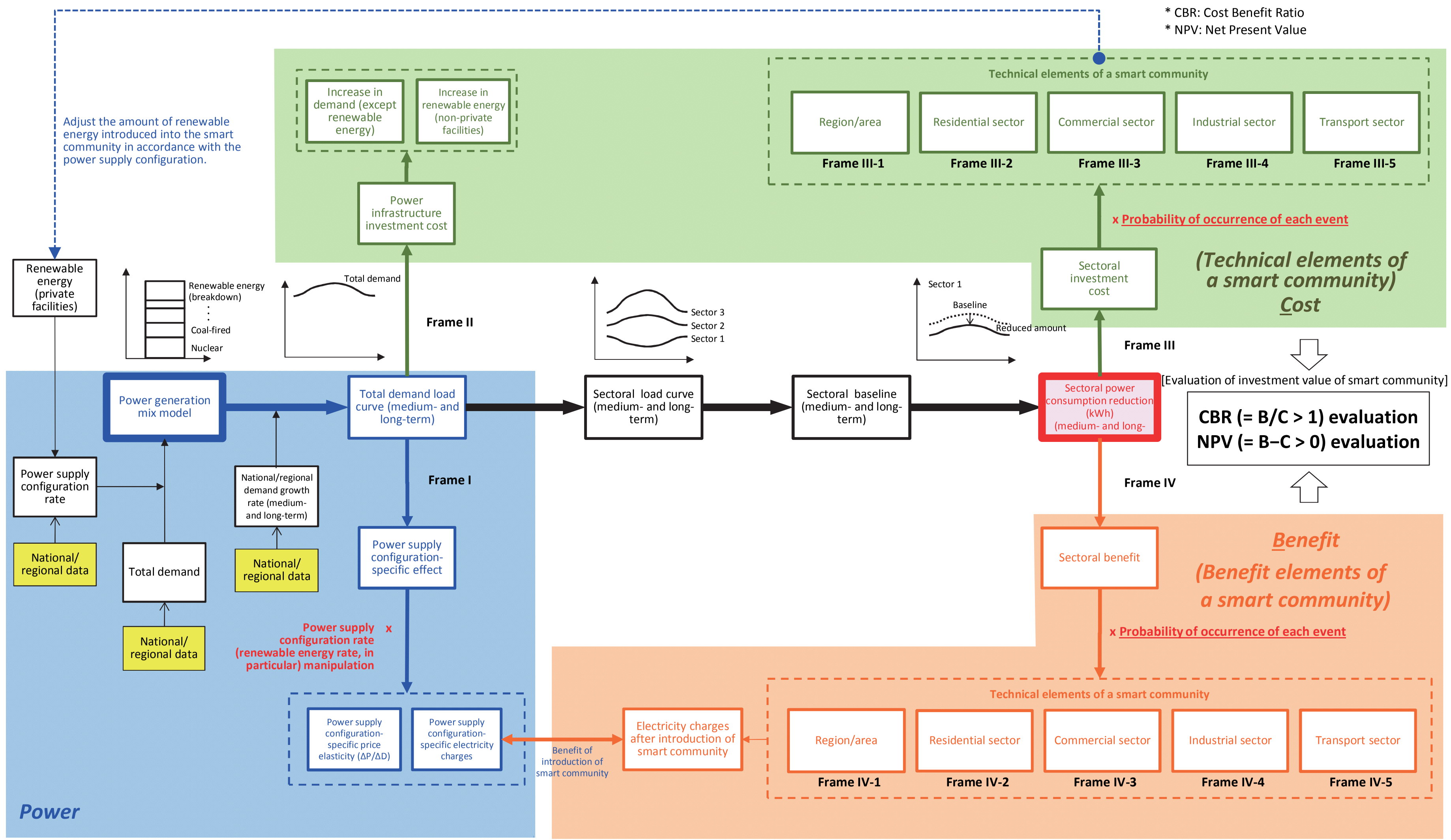
Appendix: Static Frameworks for Costs and Benefits of a Smart Community

Static Frameworks for Costs and Benefits of a Smart Community

1	Whole	Basic frame



Notes

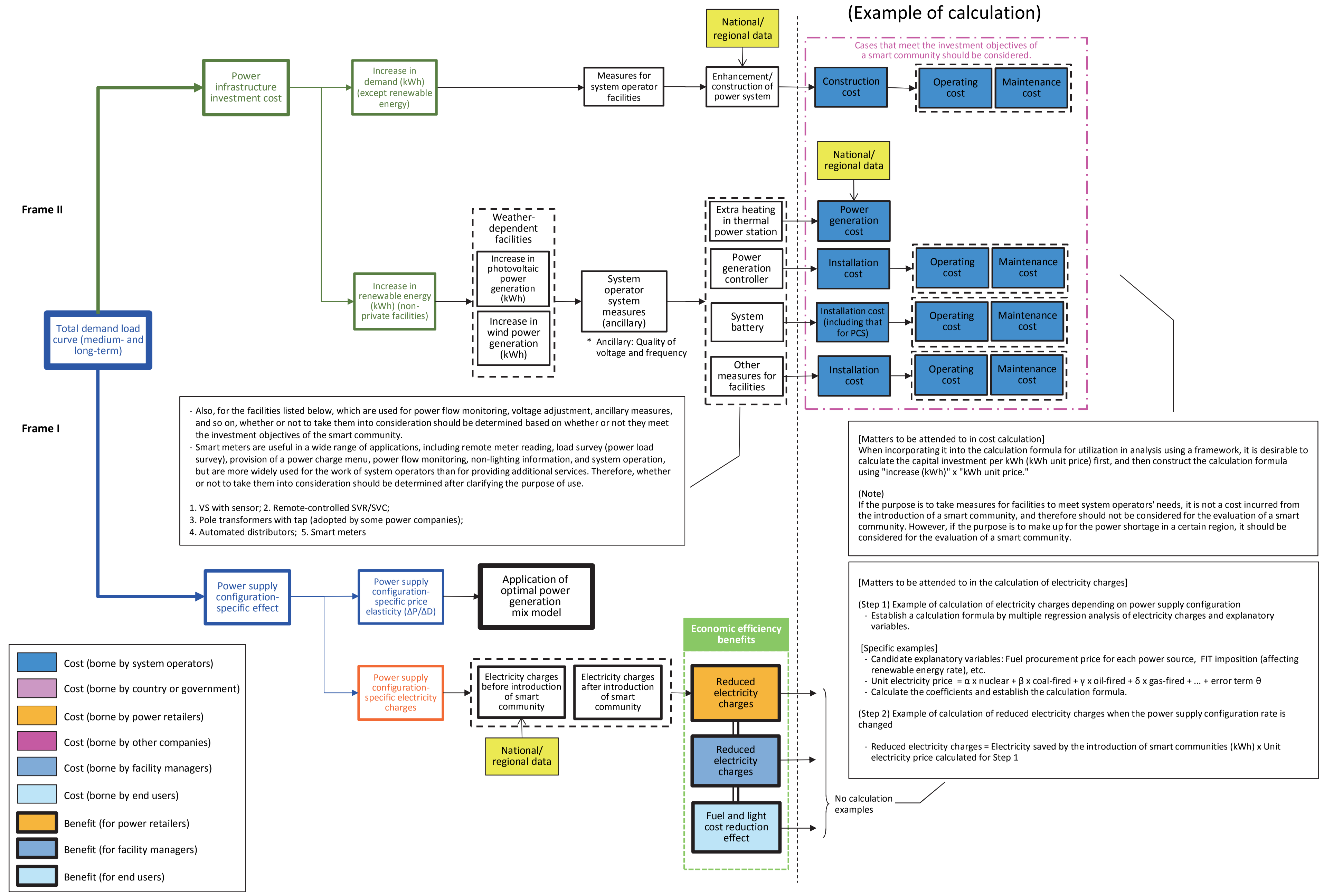
(1) A smart community is defined as the construction of a social infrastructure using a well-balanced 3E approach (energy security, economic efficiency, and environment protection) through energy management utilizing ICT.
(2) Focusing on the amount of reduced power consumption as a visible effect of energy management, the cost and benefit items for all stakeholders should be sorted out for 3E.
(3) Also, the framework for each stakeholder is useful for evaluating the investment value.
(4) An example of the calculation of the monetary value is given for some items.
(5) If it is difficult to calculate the monetary value as in the example, reorganize the calculation items or use the with-without method, which compares the total cost before and after the introduction of a certain event.
(6) Items that cannot be converted into monetary values should be evaluated, for instance, by scores based on their importance (importance evaluation).

[Example of utilization of this framework]
(Example 1) Examine the influence on the costs and benefits when the power supply configuration is changed.
(Example 2) Determine the (optimum) power supply configuration by changing the costs and benefits.

Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

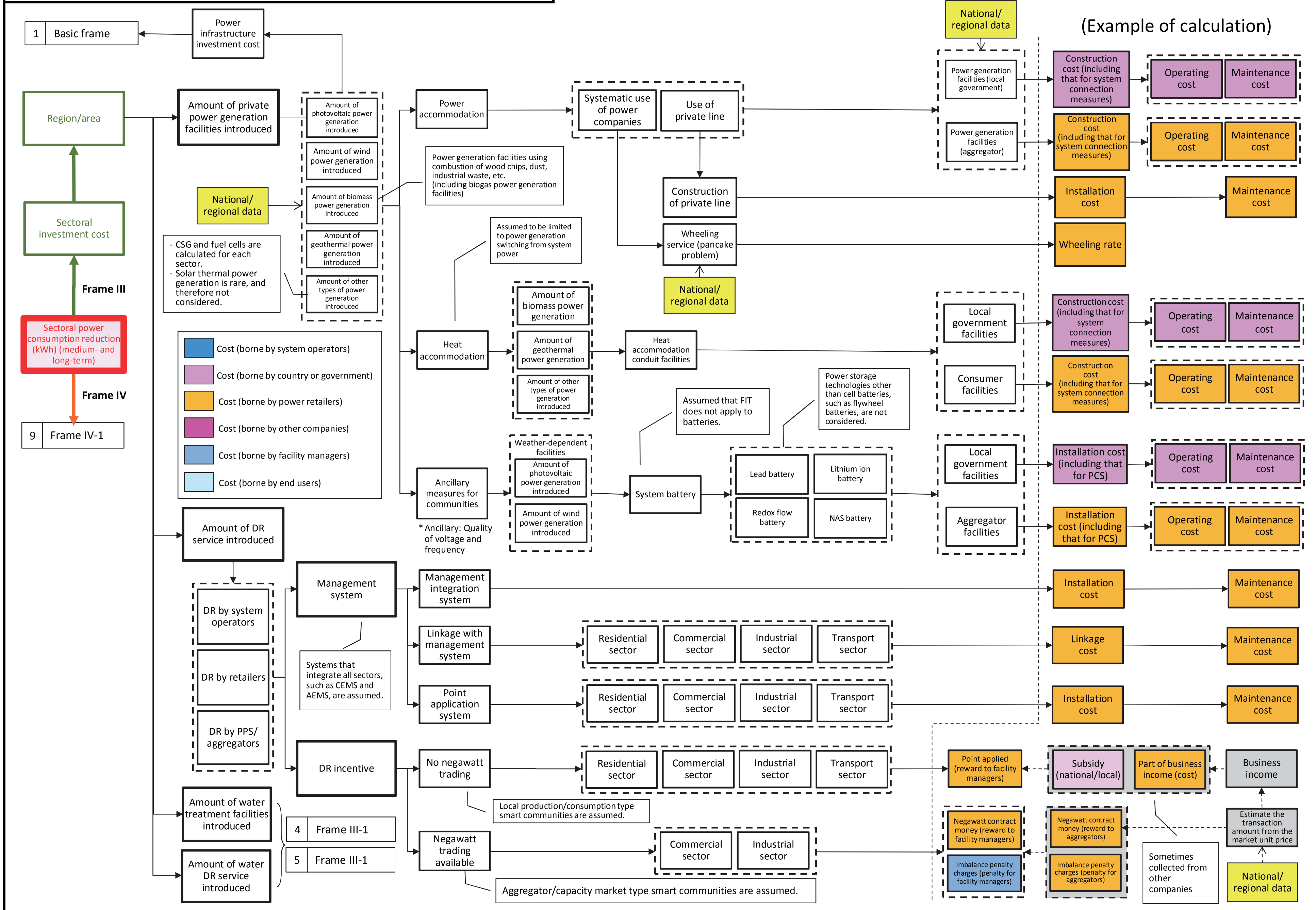
2	Costs	Frame I Frame II



Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

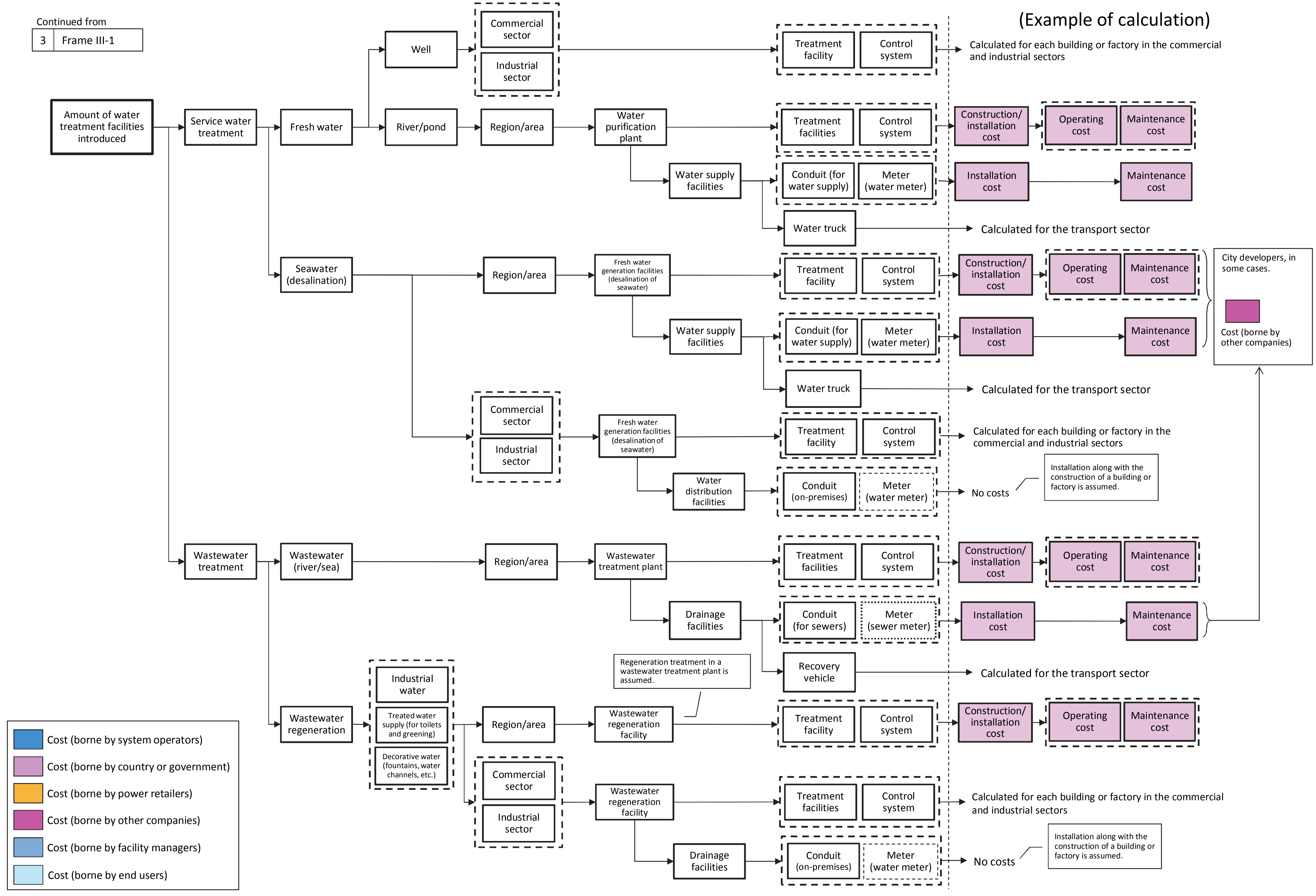
3	Costs	Frame III-1 (Region/area 1)



Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

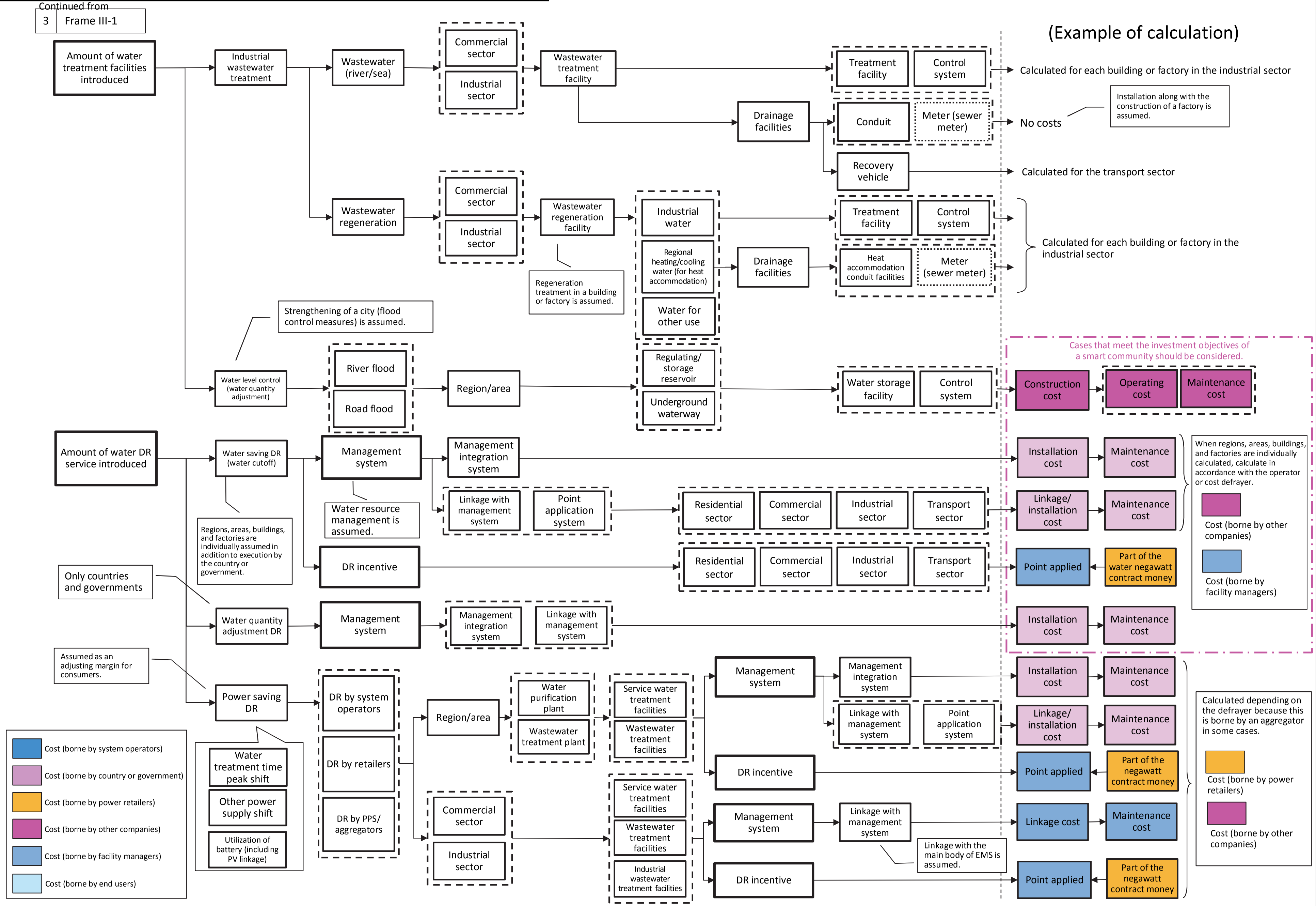
4	Costs	Frame III-1 (Region/area 2)



Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

5	Costs	Frame III-1 (Region/area 3)

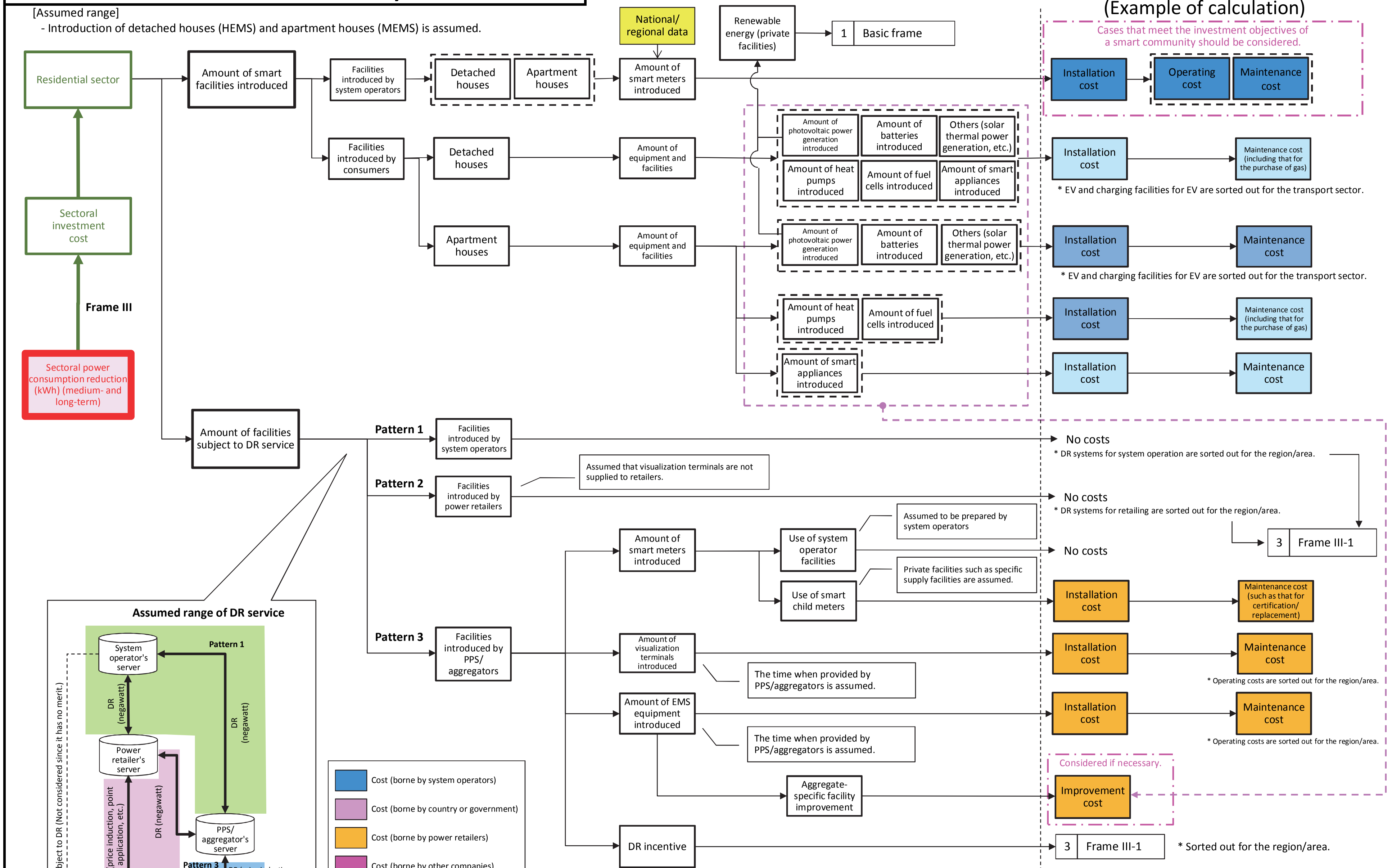


Static Frameworks for Costs and Benefits of a Smart Community

6	Costs	Frame III-2 (Residential sector)

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

[Assumed range]
- Introduction of detached houses (HEMS) and apartment houses (MEMS) is assumed.



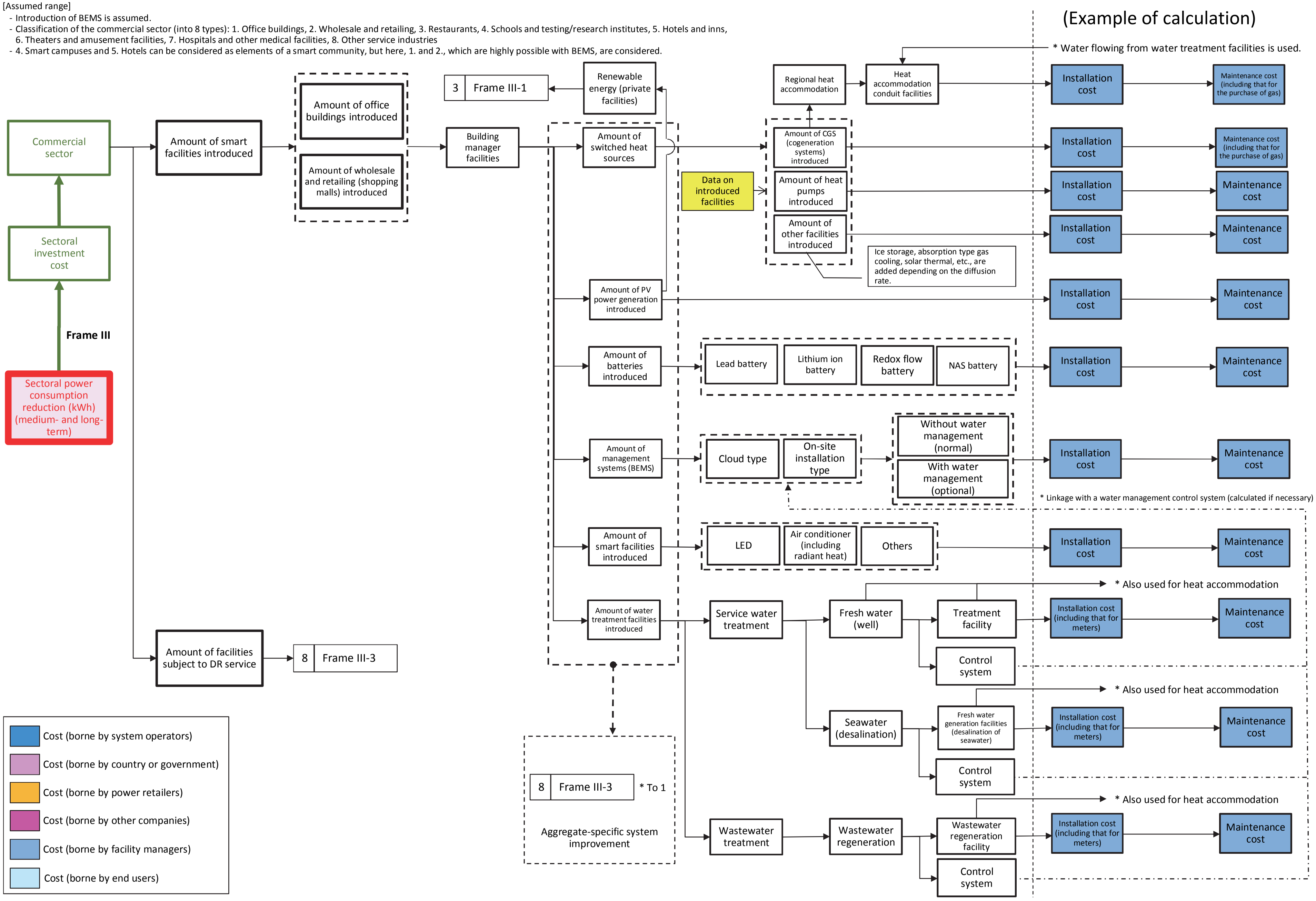
[Matters to be attended to in cost calculation]
- Calculate the capital investment per kWh (kWh unit price) first, then construct the calculation formula using "Sectoral power consumption reduced (kWh)" x "kWh unit price.
- If it is difficult to calculate each cost individually, reorganize and calculate the costs comprehensively.

Static Frameworks for Costs and Benefits of a Smart Community

7	Costs	Frame III-3 (Commercial sector 1)

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

[Assumed range]
- Introduction of BEMS is assumed.
- Classification of the commercial sector (into 8 types): 1. Office buildings, 2. Wholesale and retailing, 3. Restaurants, 4. Schools and testing/research institutes, 5. Hotels and inns, 6. Theaters and amusement facilities, 7. Hospitals and other medical facilities, 8. Other service industries
- 4. Smart campuses and 5. Hotels can be considered as elements of a smart community, but here, 1. and 2., which are highly possible with BEMS, are considered.

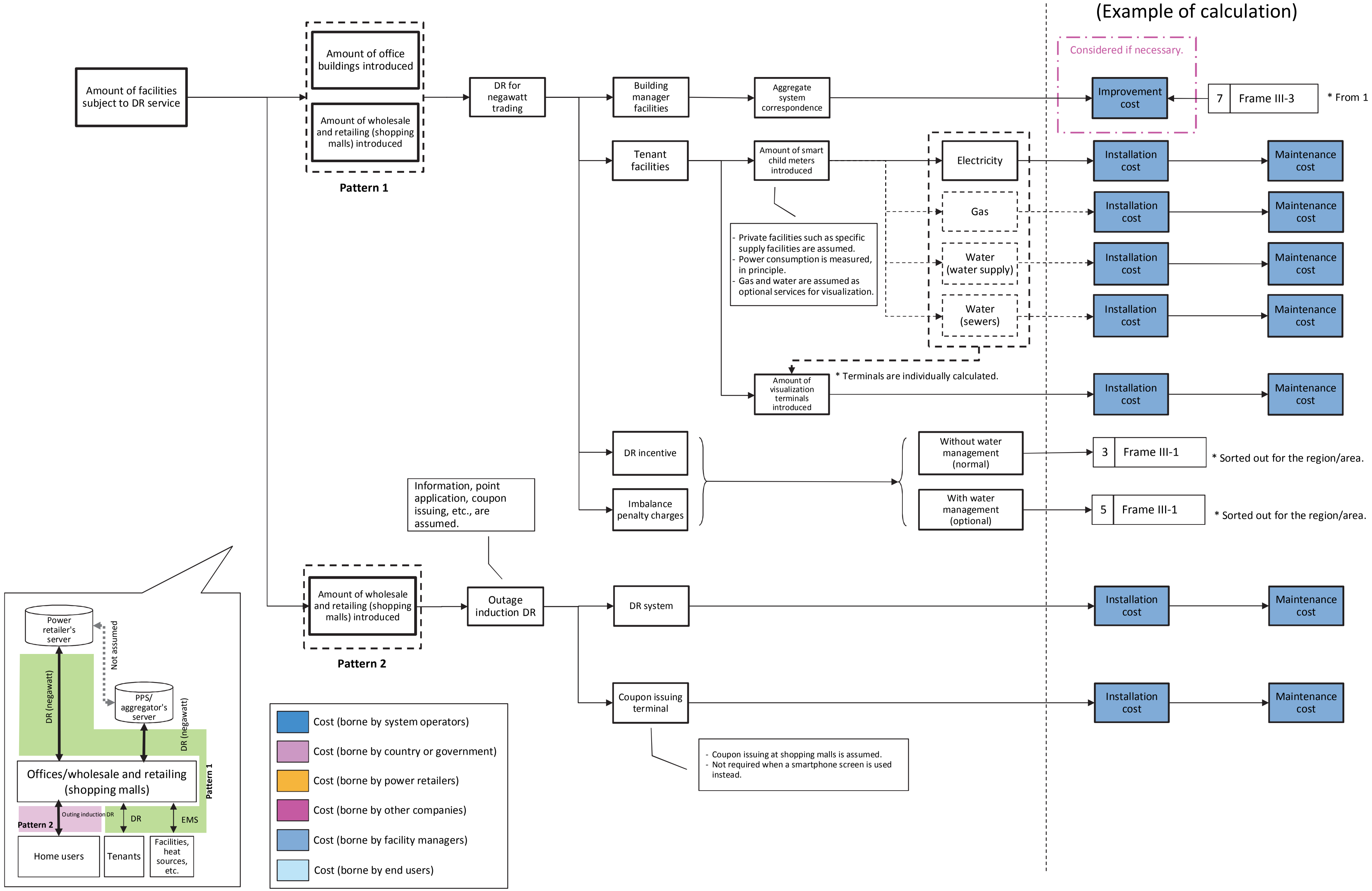


Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

8	Costs	Frame III-3 (Commercial sector 2)

[Assumed range]
- Introduction of BEMS is assumed.
- Classification of the commercial sector (into 8 types): 1. Office buildings, 2. Wholesale and retailing, 3. Restaurants, 4. Schools and testing/research institutes, 5. Hotels and inns, 6. Theaters and amusement facilities, 7. Hospitals and other medical facilities, 8. Other service industries
- 4. Smart campuses and 5. Hotels can be considered as elements of a smart community, but here, 1. and 2., which are highly possible with BEMS, are considered.



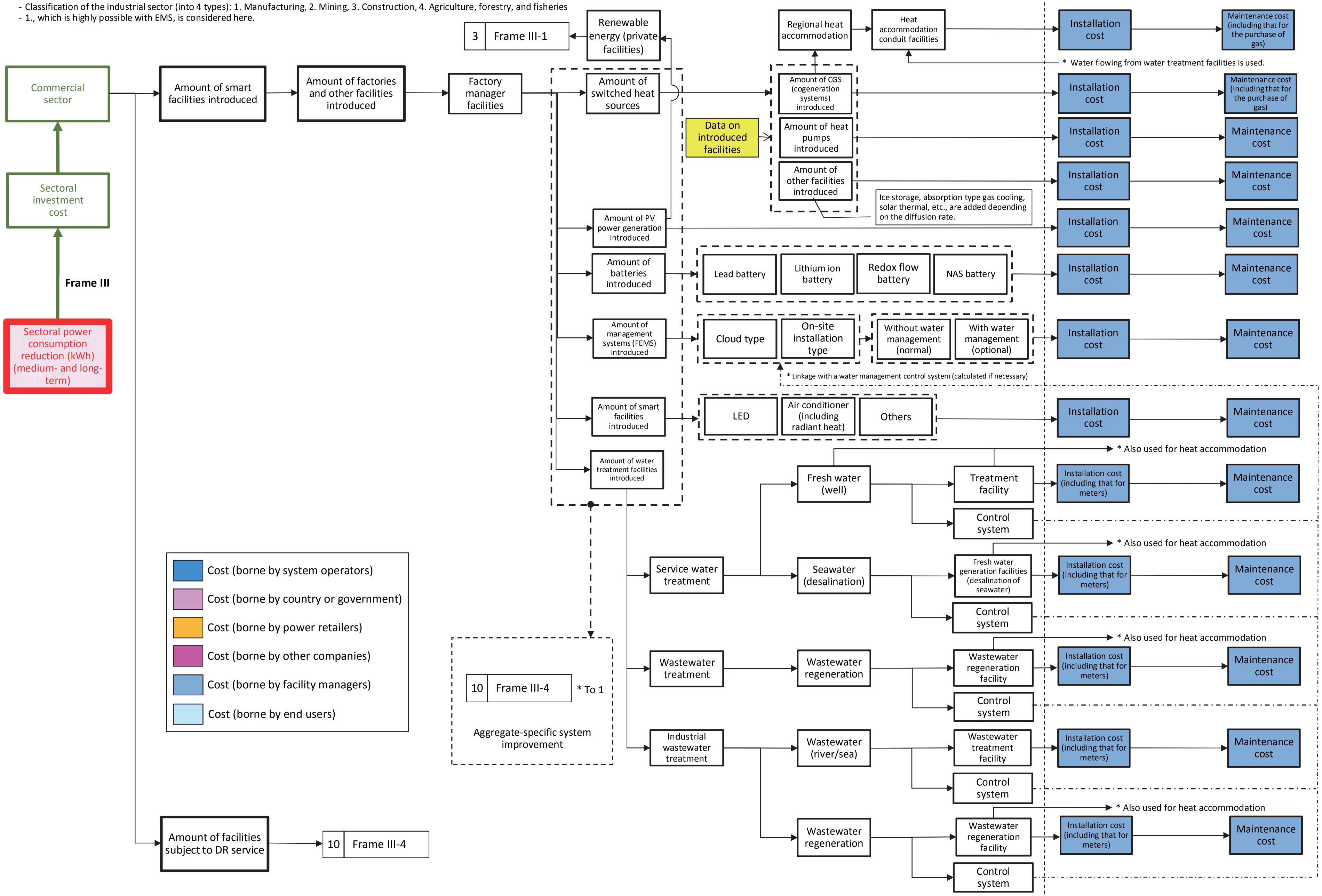
Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

9	Costs	Frame III-4 (Industrial sector 1)

[Assumed range]
- Introduction of FEMS is assumed.
- Classification of the industrial sector (into 4 types): 1. Manufacturing, 2. Mining, 3. Construction, 4. Agriculture, forestry, and fisheries
- 1., which is highly possible with EMS, is considered here.

(Example of calculation)



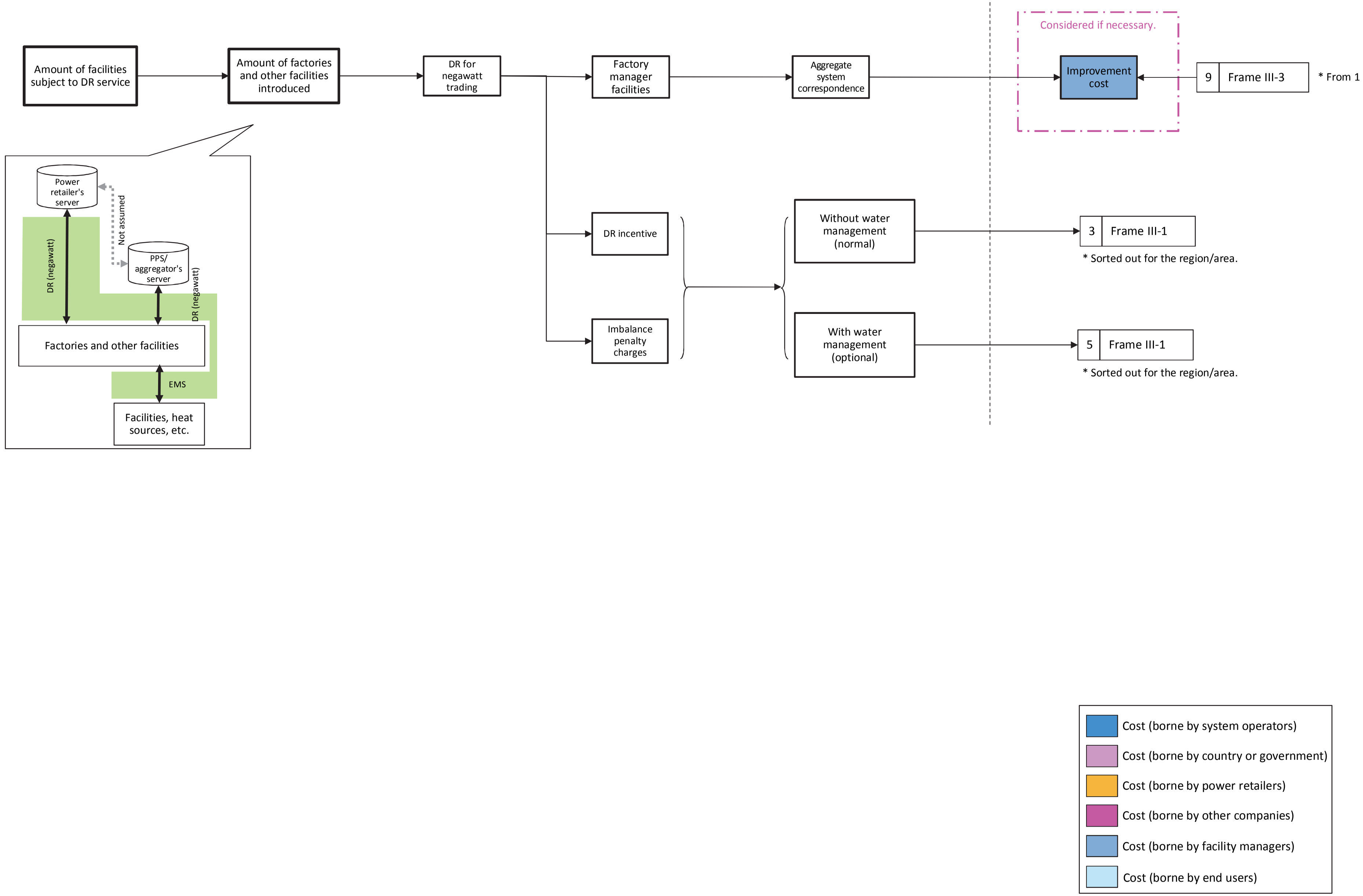
Static Frameworks for Costs and Benefits of a Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

10	Costs	Frame III-4 (Industrial sector 2)

[Assumed range]
- Introduction of FEMS is assumed.
- Classification of the industrial sector (into 4 types): 1. Manufacturing, 2. Mining, 3. Construction, 4. Agriculture, forestry, and fisheries
- 1., which is highly possible with EMS, is considered here.

(Example of calculation)



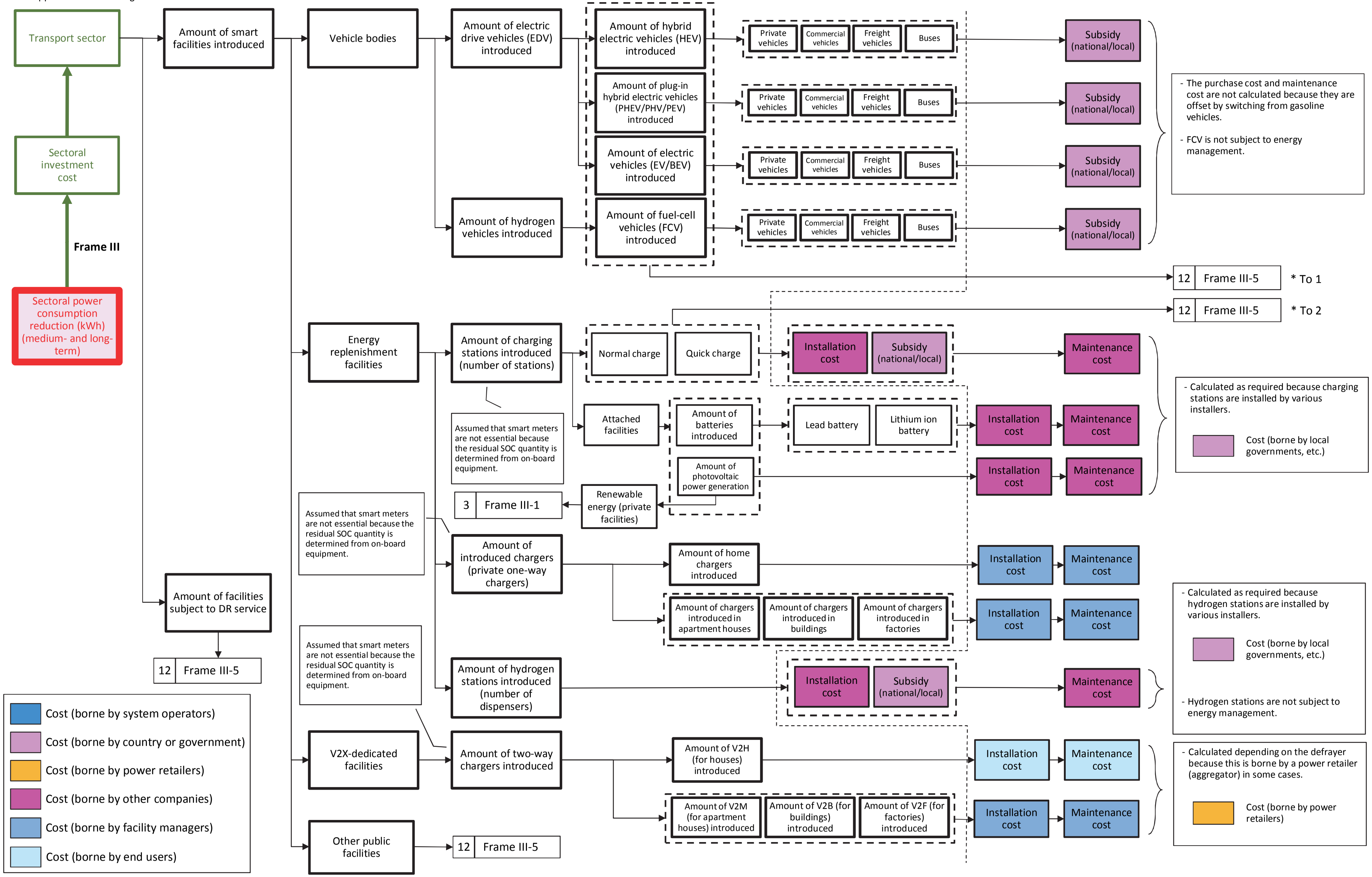
Static Frameworks for Costs and Benefits of Smart Community

11	Costs	Frame III-5 (Transport sector 1)

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

[Assumed range]
- Classification of the transport sector (into 4 types): 1. Vehicles (private passenger vehicles, commercial passenger vehicles, private freight vehicles, commercial freight vehicles), 2. Railways, 3. Ships, 4. Aviation
- 2. LRT (Light Rail Transit) and 3. Electrification of fishing boats can be considered as elements of a smart community, but 1., which is highly possible with EMS, is considered here since 2. is one of the modal shifts and 3. only applies to a limited range.

(Example of calculation)



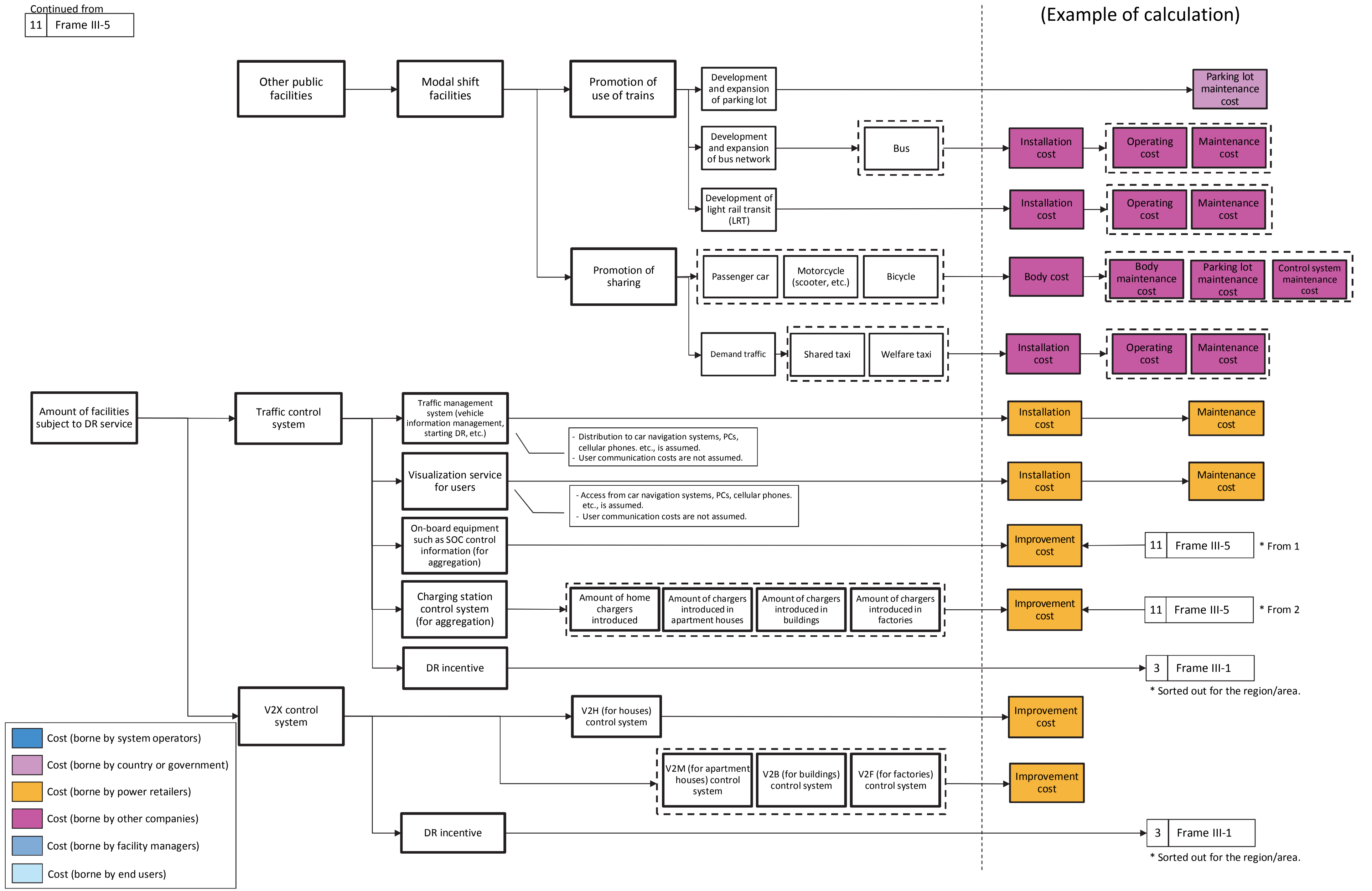
Static Frameworks for Costs and Benefits of Smart Community

(Notes)
- Capital investment in the management required for efficient use of energy in a certain region should be considered.
- Capital investment in anything other than smart communities, such as enhancement of the functions of existing facilities, should not be considered.

12	Costs	Frame III-5 (Transport sector 2)

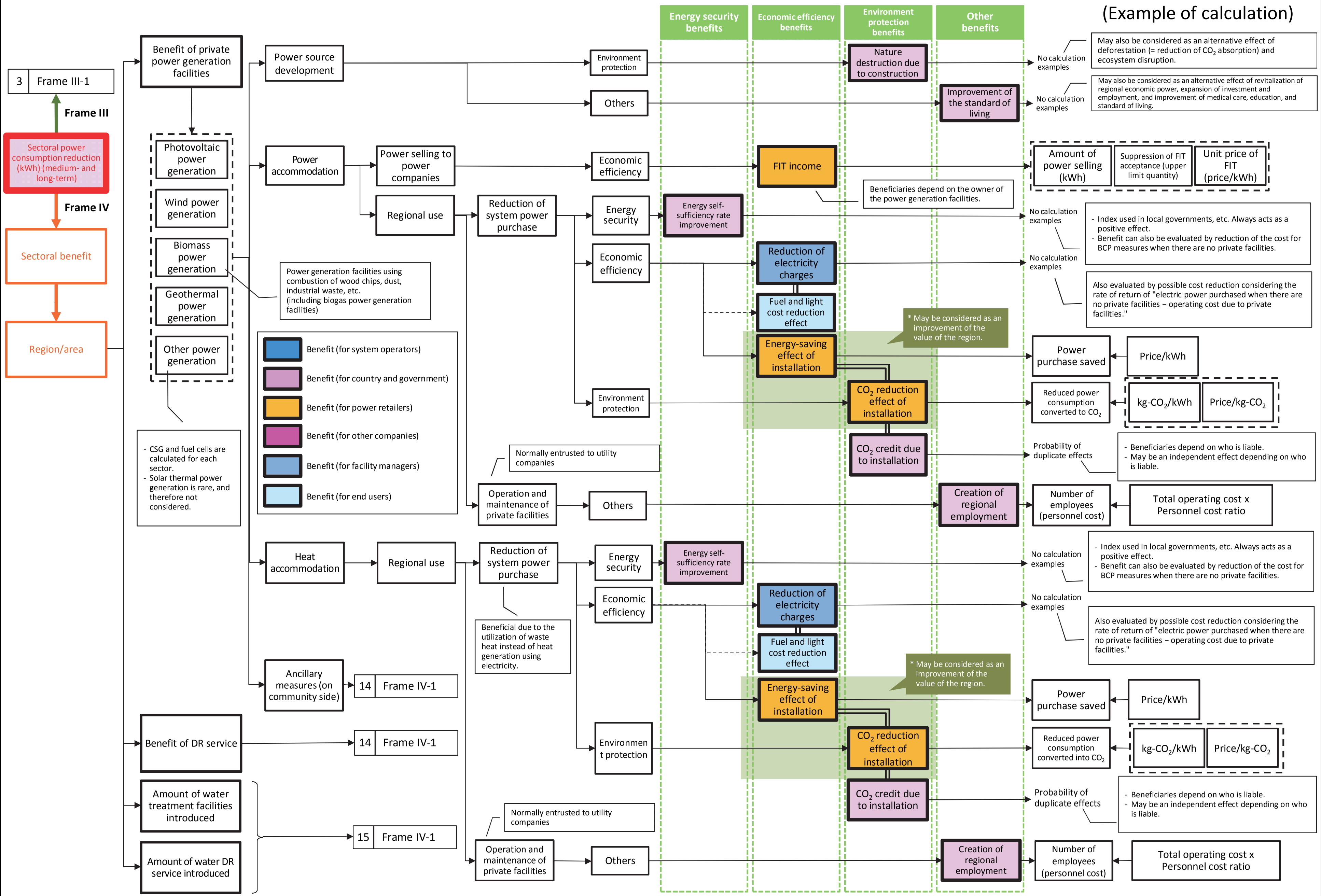
[Assumed range]
- Classification of the transport sector (into 4 types): 1. Vehicles (private passenger vehicles, commercial passenger vehicles, private freight vehicles, commercial freight vehicles), 2. Railways, 3. Ships, 4. Aviation
- 2. LRT (Light Rail Transit) and 3. Electrification of fishing boats can be considered as elements of a smart community, but 1., which is highly possible with EMS, is considered here since 2. is one of the modal shifts and 3. only applies to a limited range.

Continued from 11 Frame III-5



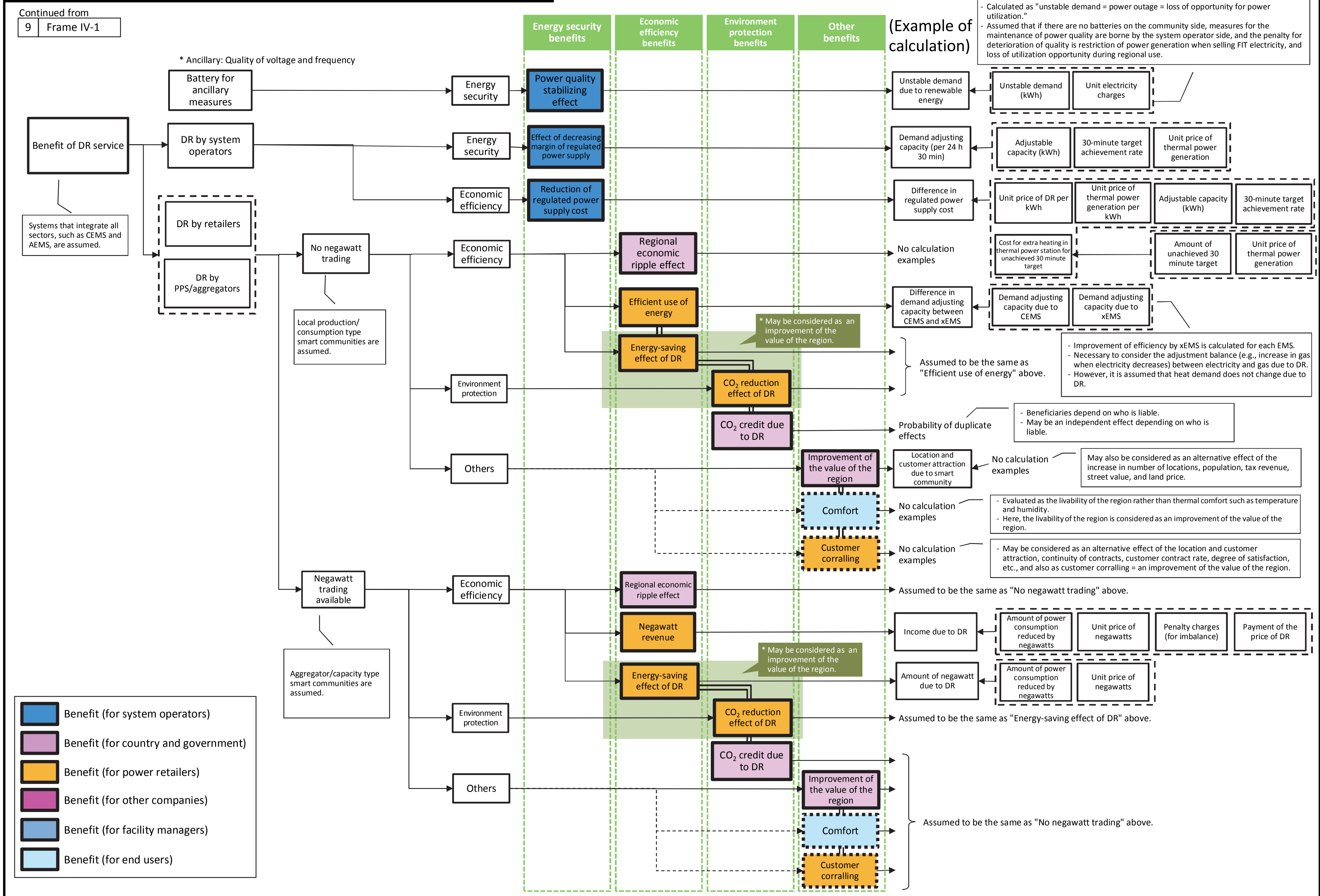
Static Frameworks for Costs and Benefits of a Smart Community

13	Benefits	Frame IV-1 (Region/area 1)



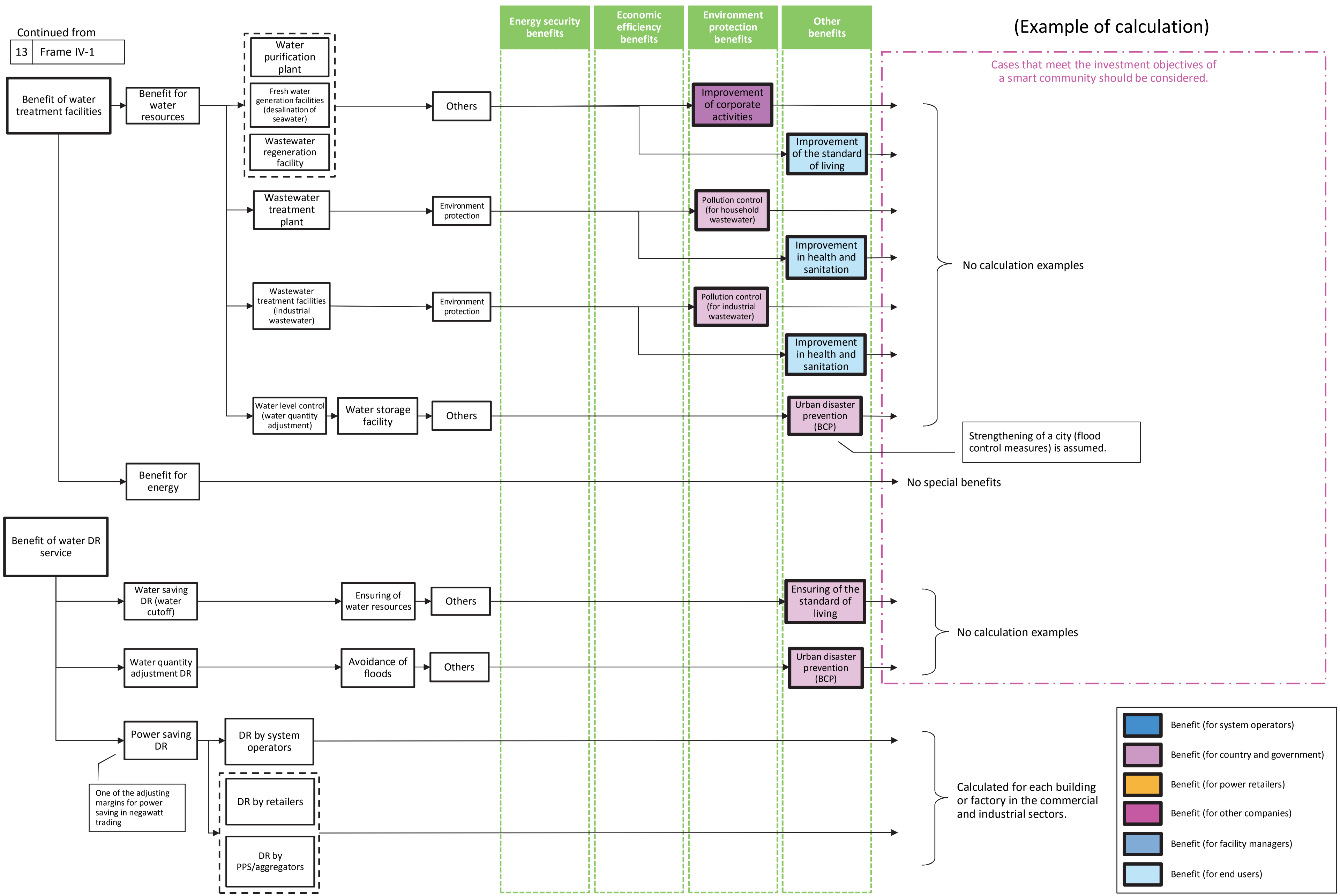
Static Frameworks for Costs and Benefits of a Smart Community

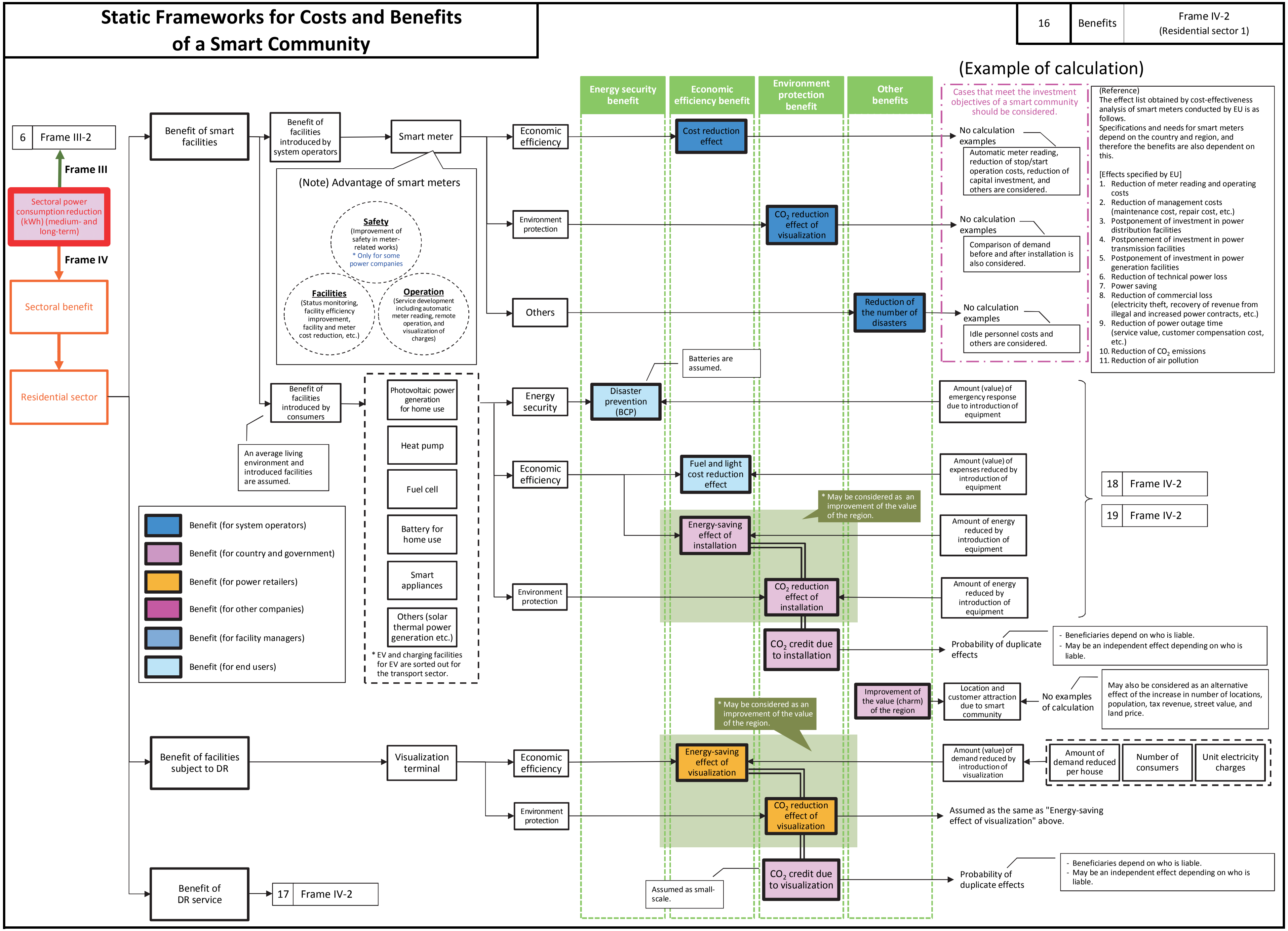
14	Benefits	Frame IV-1 (Region/area 2)



Static Frameworks for Costs and Benefits of a Smart Community

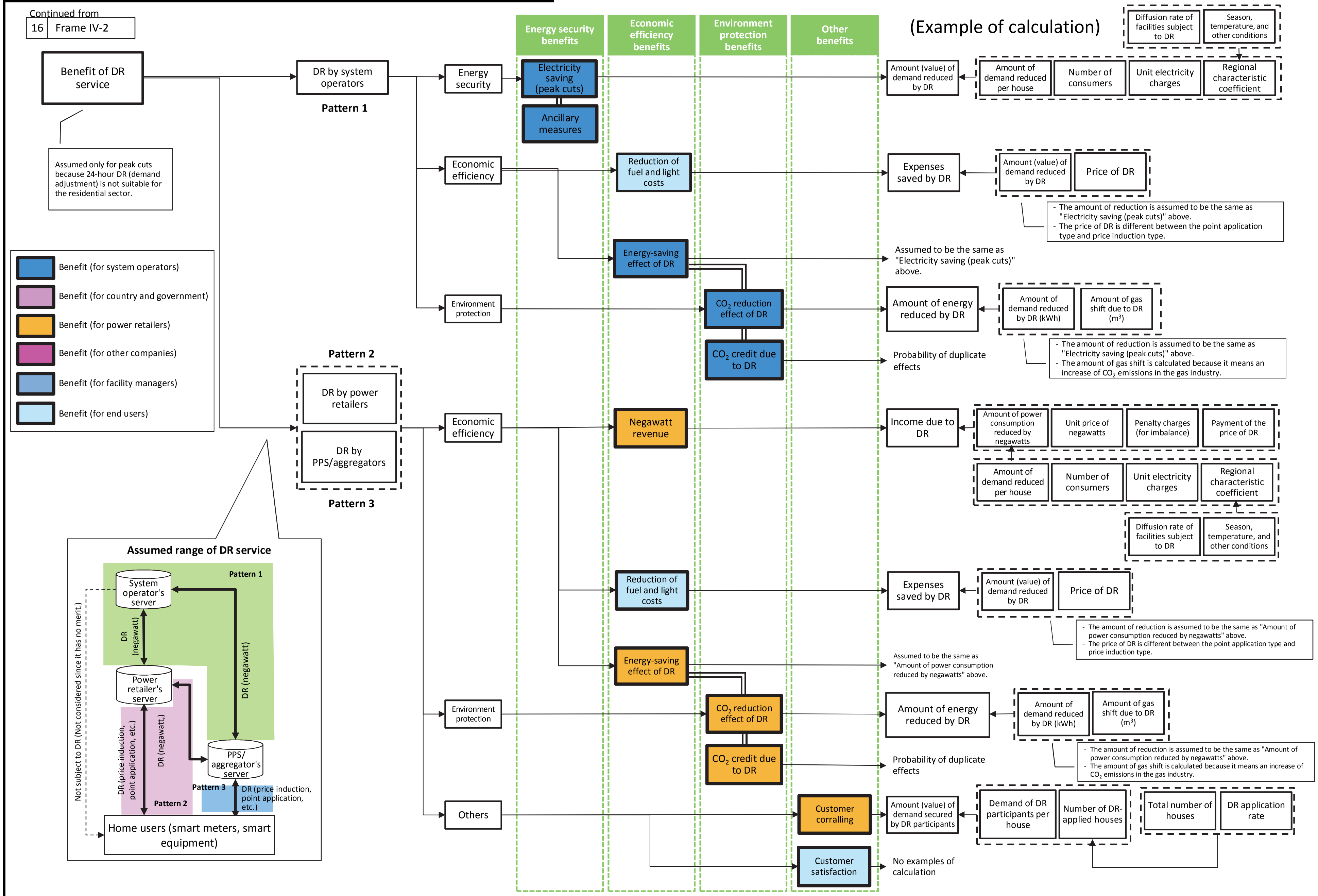
15	Benefits	Frame IV-1 (Region/area 3)




Static Frameworks for Costs and Benefits of a Smart Community
16 Benefits Frame IV-2 (Residential sector 1)
(Example of calculation)
6 Frame III-2
Frame III
Sectoral power consumption reduction (kWh) (medium- and long-term)
Frame IV
Sectoral benefit
Residential sector
Benefit of smart facilities
Benefit of facilities introduced by system operators
Smart meter
(Note) Advantage of smart meters
Safety (Improvement of safety in meter-related works) * Only for some power companies
Facilities (Status monitoring, facility efficiency improvement, facility and meter cost reduction, etc.)
Operation (Service development including automatic meter reading, remote operation, and visualization of charges)
Benefit of facilities introduced by consumers
An average living environment and introduced facilities are assumed.
Photovoltaic power generation for home use
Heat pump
Fuel cell
Battery for home use
Smart appliances
Others (solar thermal power generation etc.)
* EV and charging facilities for EV are sorted out for the transport sector.
Benefit (for system operators)
Benefit (for country and government)
Benefit (for power retailers)
Benefit (for other companies)
Benefit (for facility managers)
Benefit (for end users)
Economic efficiency
Environment protection
Others
Energy security
Economic efficiency
Environment protection
Energy security benefit
Economic efficiency benefit
Environment protection benefit
Other benefits
Cost reduction effect
CO2 reduction effect of visualization
Reduction of the number of disasters
Batteries are assumed.
Disaster prevention (BCP)
Fuel and light cost reduction effect
* May be considered as an improvement of the value of the region.
Energy-saving effect of installation
CO2 reduction effect of installation
CO2 credit due to installation
Improvement of the value (charm) of the region
Cases that meet the investment objectives of a smart community should be considered.
No calculation examples
Automatic meter reading, reduction of stop/start operation costs, reduction of capital investment, and others are considered.
No calculation examples
Comparison of demand before and after installation is also considered.
No calculation examples
Idle personnel costs and others are considered.
(Reference)
The effect list obtained by cost-effectiveness analysis of smart meters conducted by EU is as follows.
Specifications and needs for smart meters depend on the country and region, and therefore the benefits are also dependent on this.
[Effects specified by EU]
1. Reduction of meter reading and operating costs
2. Reduction of management costs (maintenance cost, repair cost, etc.)
3. Postponement of investment in power distribution facilities
4. Postponement of investment in power transmission facilities
5. Postponement of investment in power generation facilities
6. Reduction of technical power loss
7. Power saving
8. Reduction of commercial loss (electricity theft, recovery of revenue from illegal and increased power contracts, etc.)
9. Reduction of power outage time (service value, customer compensation cost, etc.)
10. Reduction of CO2 emissions
11. Reduction of air pollution
Amount (value) of emergency response due to introduction of equipment
Amount (value) of expenses reduced by introduction of equipment
Amount of energy reduced by introduction of equipment
Amount of energy reduced by introduction of equipment
18 Frame IV-2
19 Frame IV-2
Probability of duplicate effects
- Beneficiaries depend on who is liable.
- May be an independent effect depending on who is liable.
Location and customer attraction due to smart community
No examples of calculation
May also be considered as an alternative effect of the increase in number of locations, population, tax revenue, street value, and land price.
Benefit of facilities subject to DR
Visualization terminal
Economic efficiency
Environment protection
* May be considered as an improvement of the value of the region.
Energy-saving effect of visualization
CO2 reduction effect of visualization
CO2 credit due to visualization
Assumed as small-scale.
Amount (value) of demand reduced by introduction of visualization
Amount of demand reduced per house
Number of consumers
Unit electricity charges
Assumed as the same as "Energy-saving effect of visualization" above.
Probability of duplicate effects
- Beneficiaries depend on who is liable.
- May be an independent effect depending on who is liable.
Benefit of DR service
17 Frame IV-2

Static Frameworks for Costs and Benefits of a Smart Community

Continued from 16 Frame IV-2

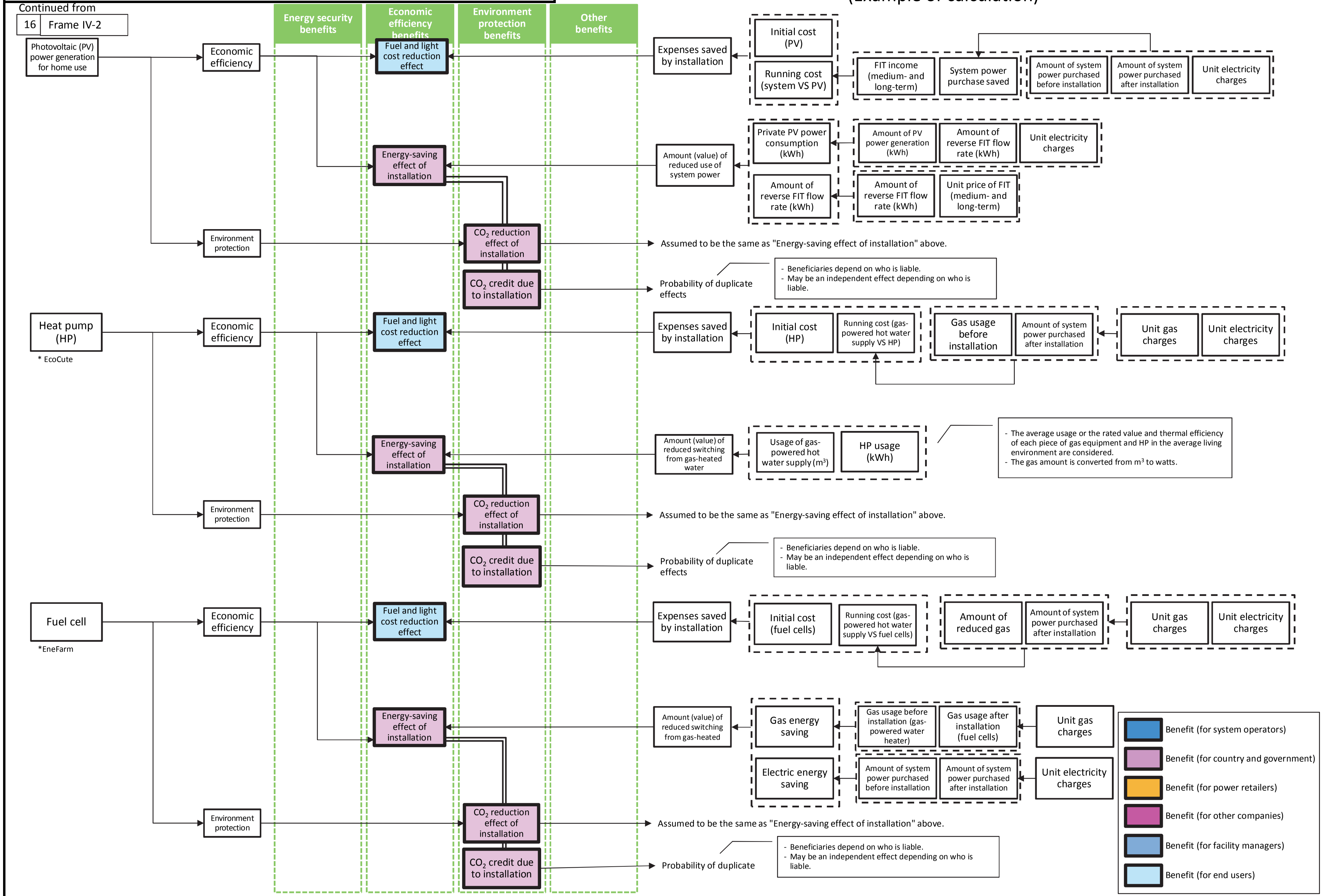


Static Frameworks for Costs and Benefits of a Smart Community

18	Benefits	Frame IV-2 (Residential sector 3)

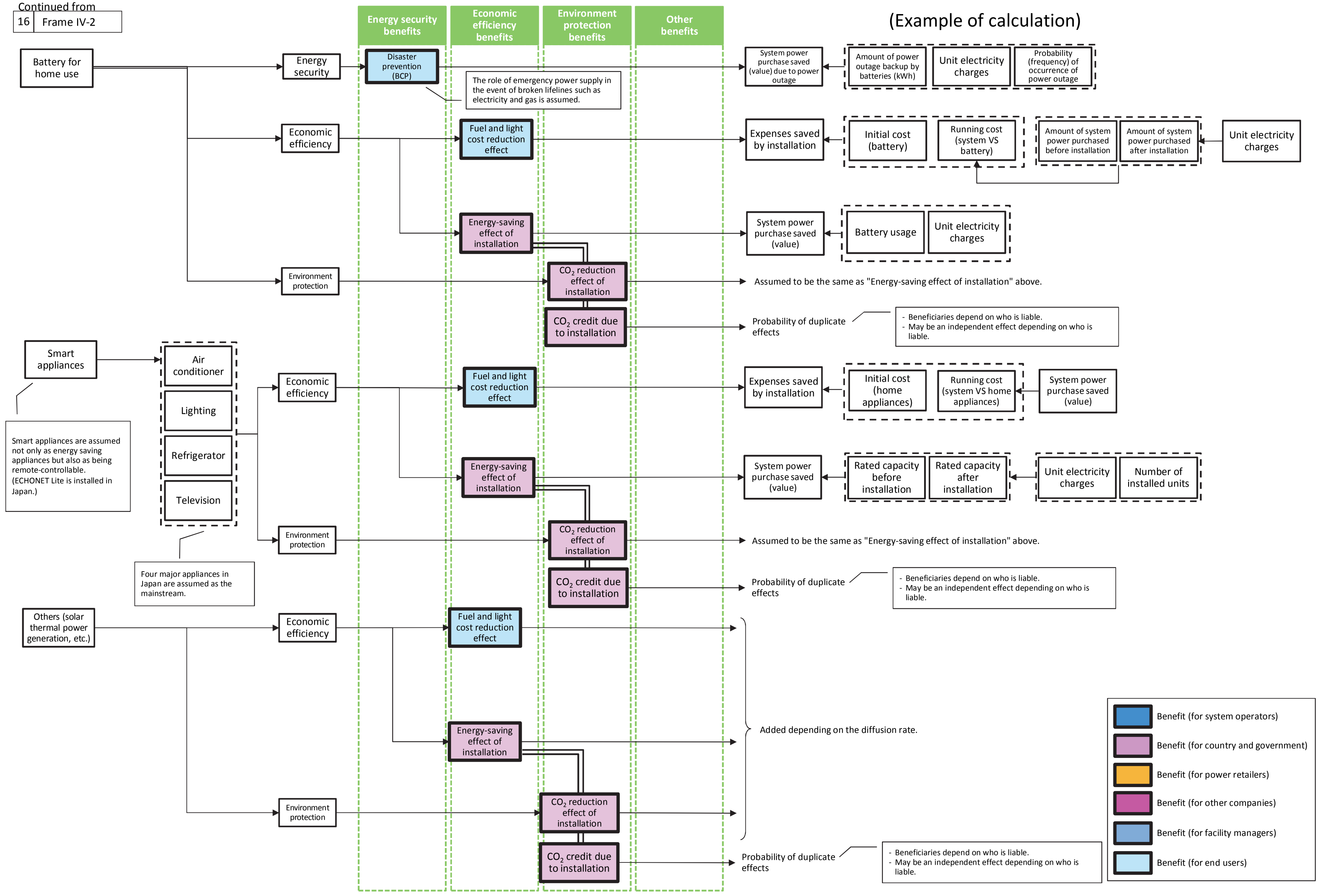
(Example of calculation)

Continued from 16 Frame IV-2

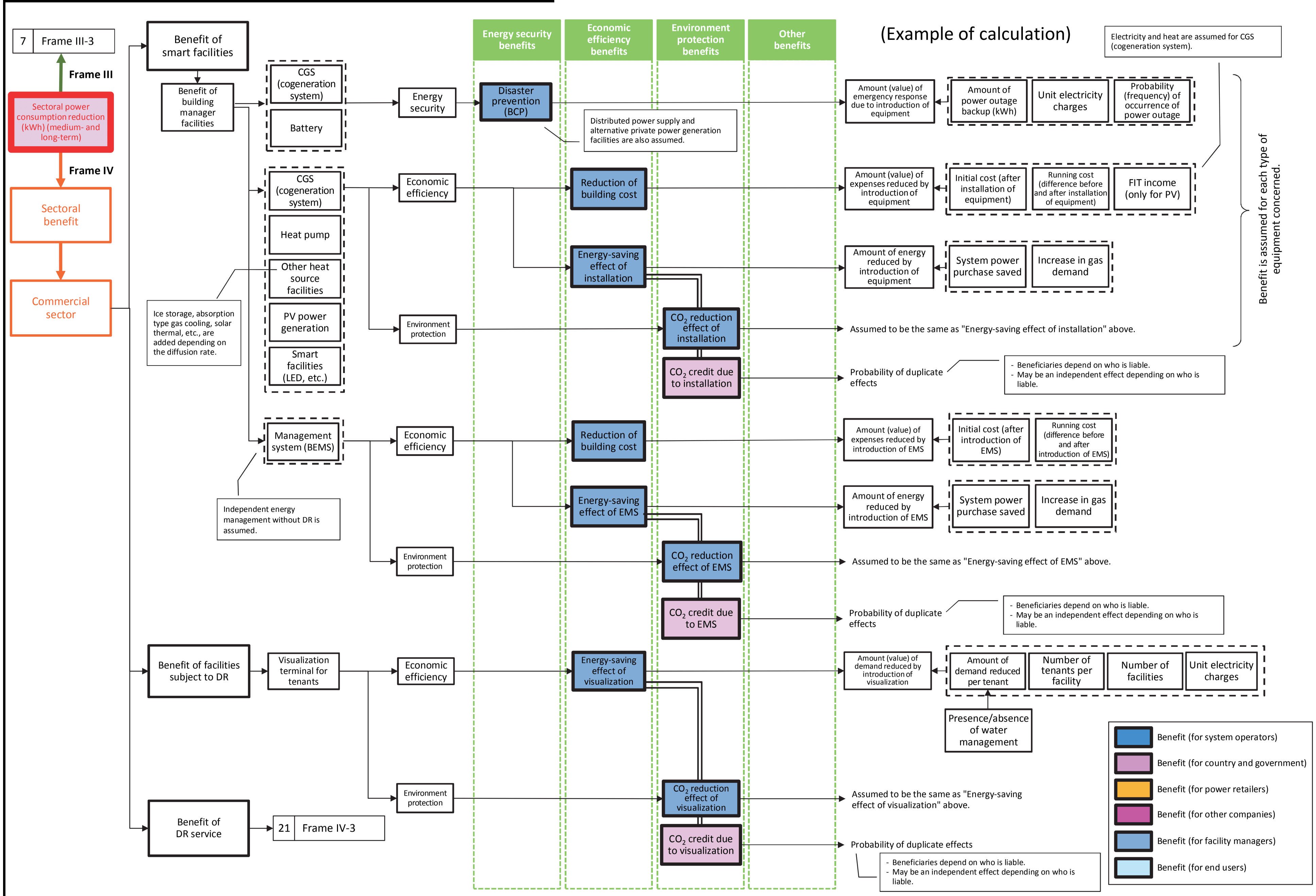


Static Frameworks for Costs and Benefits of a Smart Community

Continued from 16 Frame IV-2

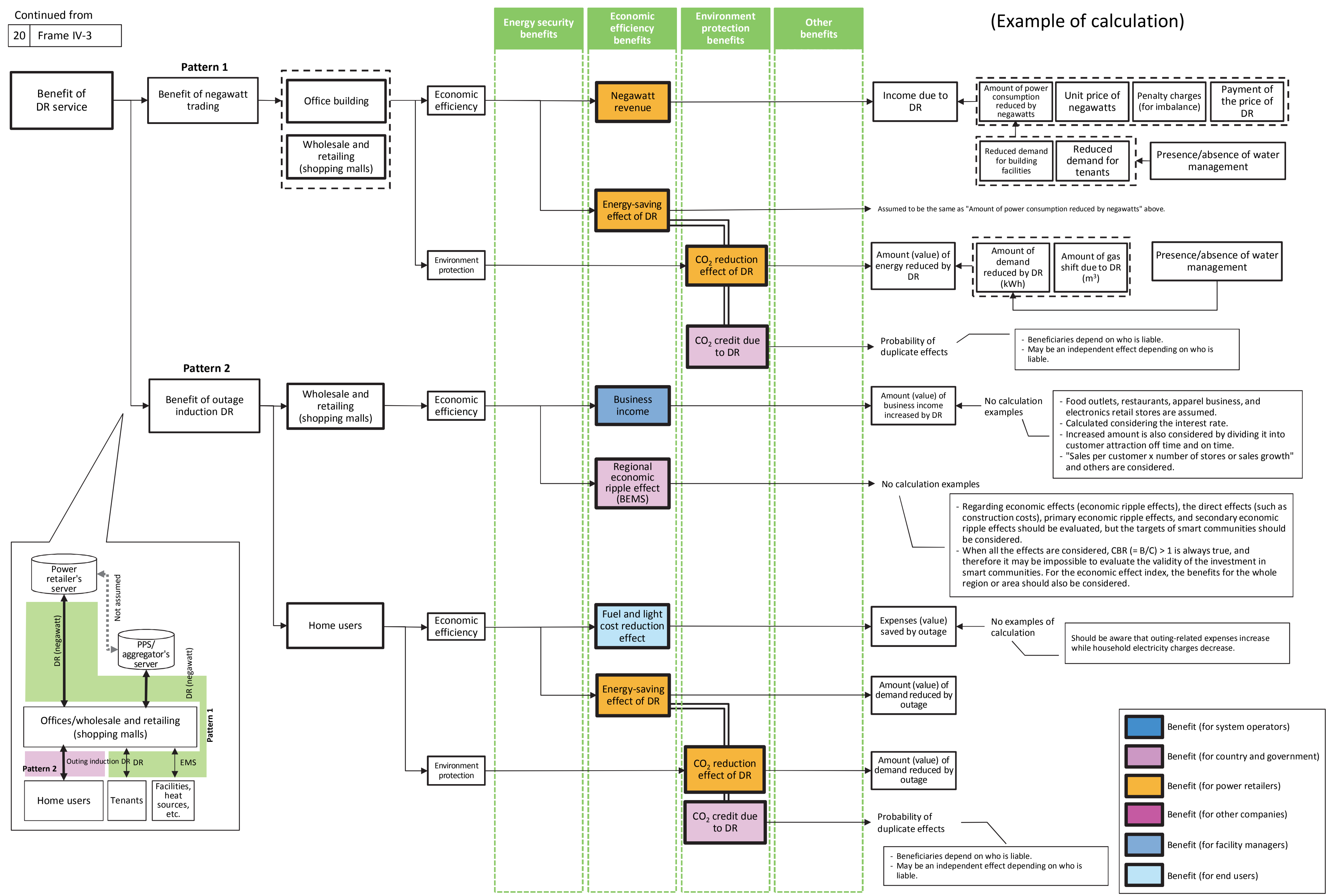


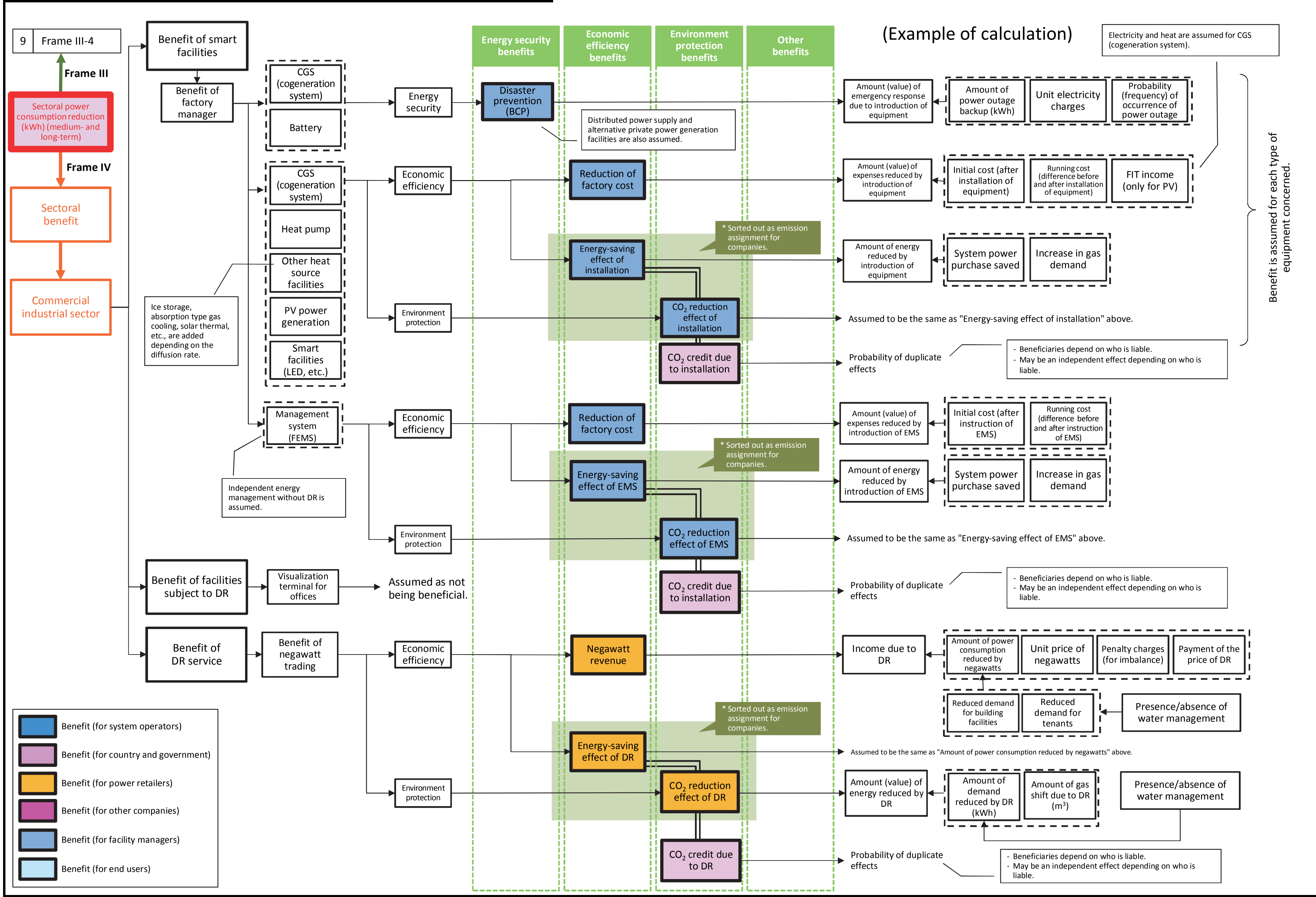
Static Frameworks for Costs and Benefits of a Smart Community



Static Frameworks for Costs and Benefits of a Smart Community

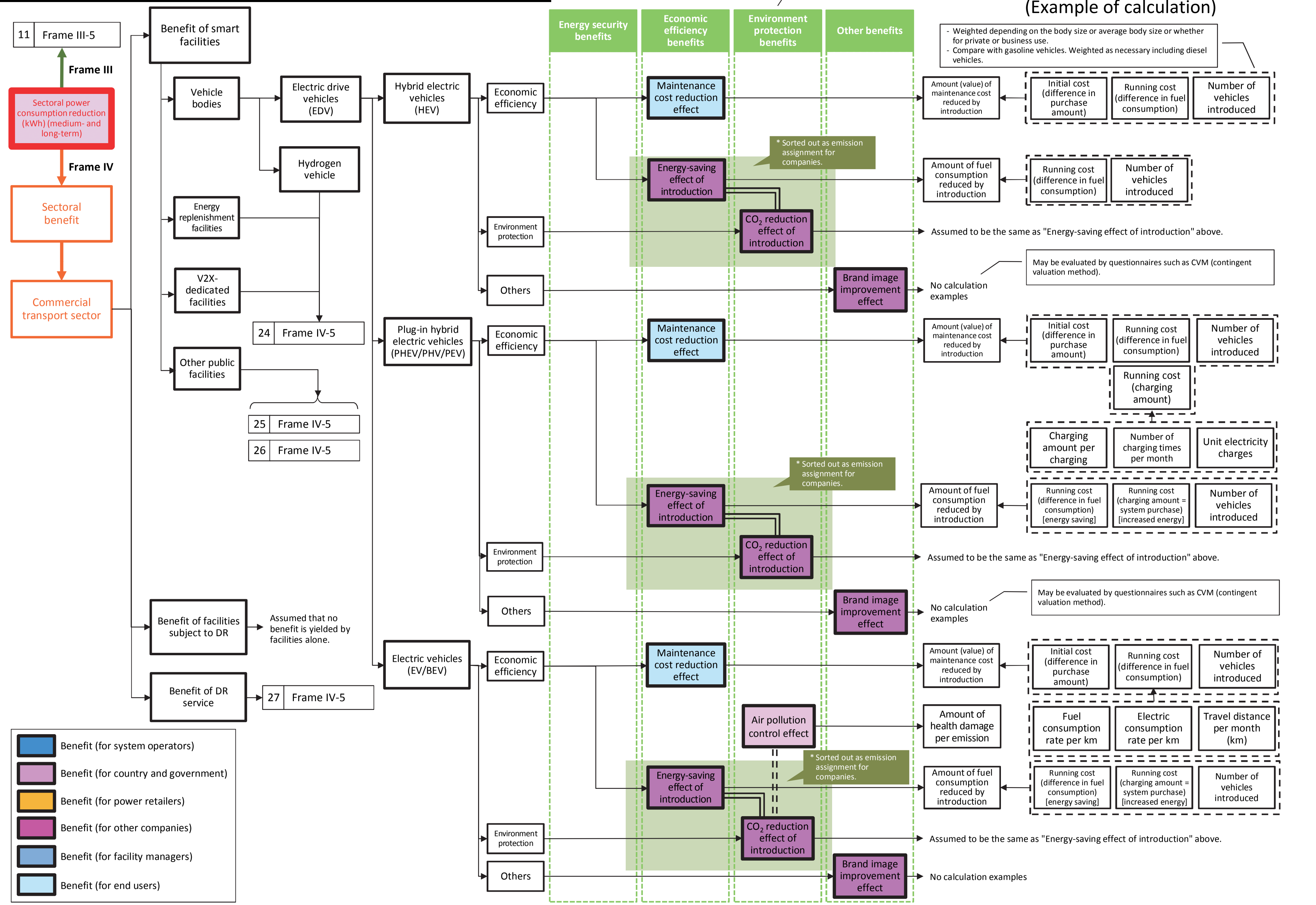
Continued from 20 Frame IV-3




9 Frame III-4
Frame III
Sectoral power consumption reduction (kWh) (medium- and long-term)
Frame IV
Sectoral benefit
Commercial industrial sector
Benefit of smart facilities
Benefit of factory manager
CGS (cogeneration system)
Battery
Energy security
CGS (cogeneration system)
Heat pump
Other heat source facilities
PV power generation
Smart facilities (LED, etc.)
Economic efficiency
Environment protection
Ice storage, absorption type gas cooling, solar thermal, etc., are added depending on the diffusion rate.
Management system (FEMS)
Independent energy management without DR is assumed.
Benefit of facilities subject to DR
Visualization terminal for offices
Assumed as not being beneficial.
Benefit of DR service
Benefit of negawatt trading
Energy security benefits
Economic efficiency benefits
Environment protection benefits
Other benefits
Disaster prevention (BCP)
Distributed power supply and alternative private power generation facilities are also assumed.
Reduction of factory cost
Energy-saving effect of installation
* Sorted out as emission assignment for companies.
CO_2 reduction effect of installation
CO_2 credit due to installation
Reduction of factory cost
Energy-saving effect of EMS
CO_2 reduction effect of EMS
CO_2 credit due to installation
Negawatt revenue
Energy-saving effect of DR
CO_2 reduction effect of DR
CO_2 credit due to DR
(Example of calculation)
Electricity and heat are assumed for CGS (cogeneration system).
Amount (value) of emergency response due to introduction of equipment
Amount of power outage backup (kWh)
Unit electricity charges
Probability (frequency) of occurrence of power outage
Amount (value) of expenses reduced by introduction of equipment
Initial cost (after installation of equipment)
Running cost (difference before and after installation of equipment)
FIT income (only for PV)
Amount of energy reduced by introduction of equipment
System power purchase saved
Increase in gas demand
Benefit is assumed for each type of equipment concerned.
Assumed to be the same as "Energy-saving effect of installation" above.
Probability of duplicate effects
- Beneficiaries depend on who is liable.
- May be an independent effect depending on who is liable.
Amount (value) of expenses reduced by introduction of EMS
Initial cost (after instruction of EMS)
Running cost (difference before and after instruction of EMS)
Amount of energy reduced by introduction of EMS
System power purchase saved
Increase in gas demand
Assumed to be the same as "Energy-saving effect of EMS" above.
Probability of duplicate effects
- Beneficiaries depend on who is liable.
- May be an independent effect depending on who is liable.
Income due to DR
Amount of power consumption reduced by negawatts
Unit price of negawatts
Penalty charges (for imbalance)
Payment of the price of DR
Reduced demand for building facilities
Reduced demand for tenants
Presence/absence of water management
Assumed to be the same as "Amount of power consumption reduced by negawatts" above.
Amount (value) of energy reduced by DR
Amount of demand reduced by DR (kWh)
Amount of gas shift due to DR (m^3)
Presence/absence of water management
Probability of duplicate effects
- Beneficiaries depend on who is liable.
- May be an independent effect depending on who is liable.
Benefit (for system operators)
Benefit (for country and government)
Benefit (for power retailers)
Benefit (for other companies)
Benefit (for facility managers)
Benefit (for end users)

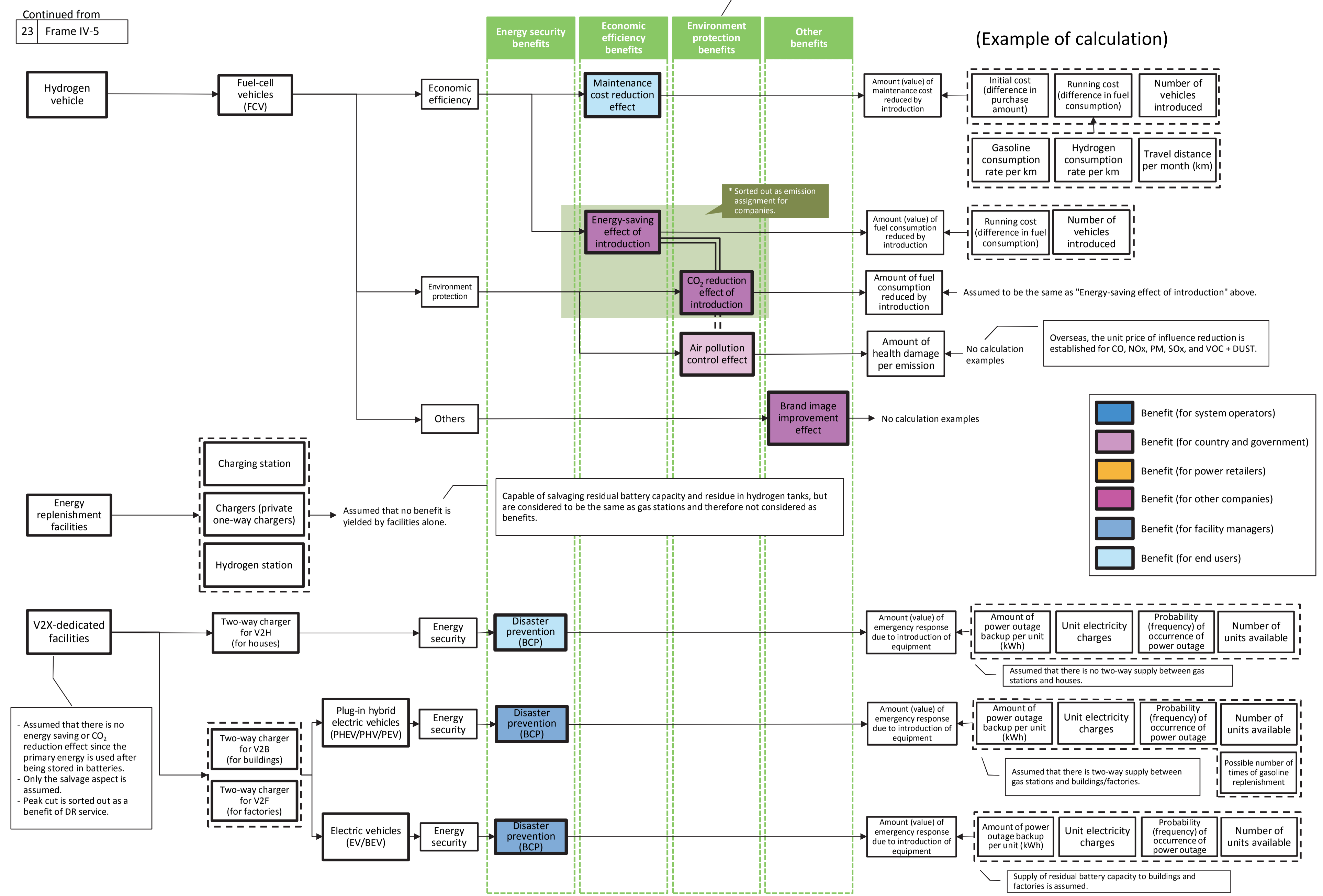
Static Frameworks for Costs and Benefits of a Smart Community

23 | Benefits | Frame IV-5 (Transport sector 1)



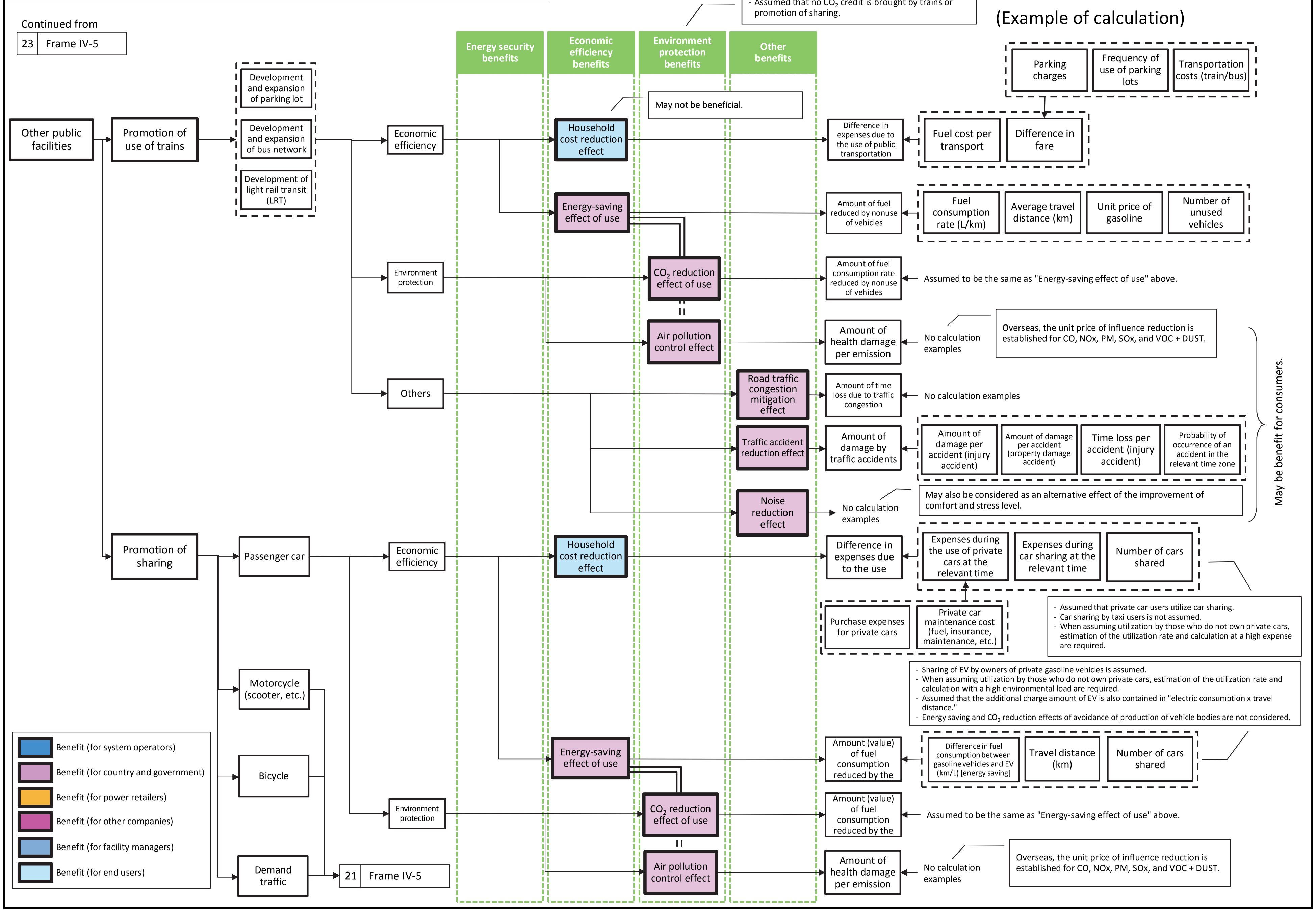
Static Frameworks for Costs and Benefits of a Smart Community

Continued from 23 Frame IV-5

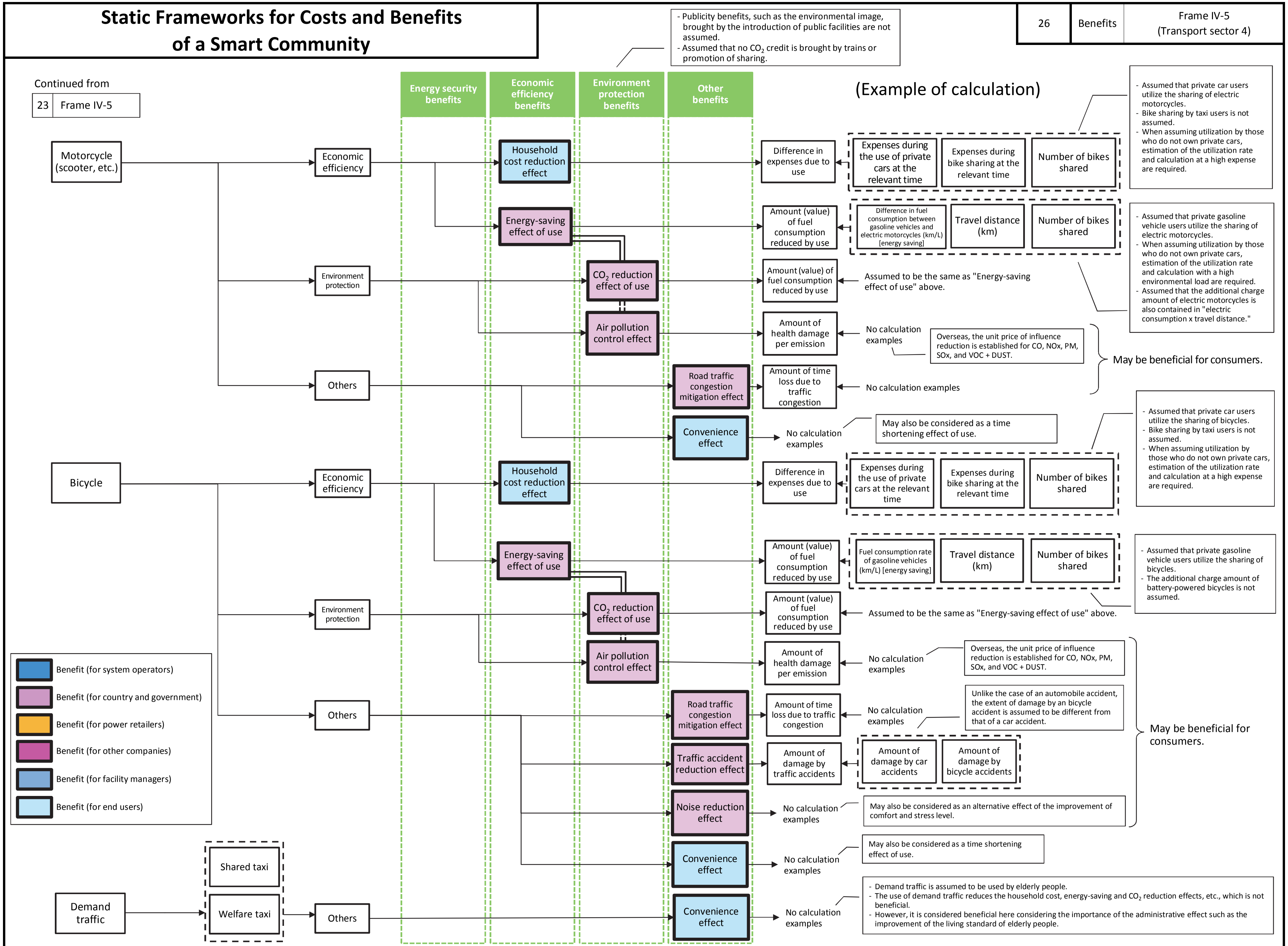


Static Frameworks for Costs and Benefits of a Smart Community

25 | Benefits | Frame IV-5 (Transport sector 3)



Static Frameworks for Costs and Benefits of a Smart Community



Static Frameworks for Costs and Benefits of a Smart Community

Continued from 23 Frame IV-5