RESEARCH ON THE OPTIMZATION OF THE DISTRICT ENERGY MIX FOR SMARTCITY OPERATION

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ABSTRACT

In this research, in order to establish efficient energy supply plan in the smart city and derive efficient operating plan considering not only distribution of classical electricity and heat resources but also CHP, geothermal and biomass which generates both electricity and heat simultaneously, the optimization is performed. The optimization is divided into two stages. First stage is deriving optimal system structure and operating strategies at the target year to achieve the city's long-term energy goals, and second stage is deriving optimal system transition for each year to reach the final target. In addition, in order to derive the optimal system structure in terms of the cost perspective, the energy resources which are already installed in the city and which can be installed in the future are modeled in terms of cost. The external factors affecting this energy resources were set as variables and reflected in the optimization process. Also, environmental factors such as CO_2 *emissions are also taken into consideration as a constraint. In order to carry out case study, the data of Naju city in Jeollanam-do, South Korea which is currently conducting Smart City project are used. The energy resources which are currently installed in Naju and potential resources are modeled and optimization is done to achieve energy independence rate of 20% or more by 2030, in order to reach national goal. As a result of the case study, the total energy demand of Naju in 2030 was estimated to be 2,190 GWh, and about 55% was covered by internal energy resources. With these results, city operator can establish a long-term energy plan for the city and operate the city with an optimized operation strategy in terms of cost.*

INTRODUCTION

Smart City is a sustainable low carbon futuristic city that integrates and manages city's resources for various purposes to reduce consumption and operating costs of energy resources while securing resilience in the event of a disaster. In Korea, various projects related to smart city are conducted by government and public organizations. Especially, in line with the government's 2030 energy policy, each local government is presenting its own energy self-reliance ratio targets and carrying out related projects. Korea Electric Power Corporation (KEPCO), Korea's leading power company, is also conducting a pilot study on the city of Naju where its headquarters is located. In order to self-supply energy independently and operate stably and efficiently, the first thing that must be preceded for smart city is to establish an optimal energy supply plan. There are many prior studies on optimal energy system planning. Most of the optimization problem were designed for planning of EMS under multiple scales [1-2]. Also, there were some research related to planning of energy system at a national scale [3-4]. However, the results of these studies are too difficult to use by city operators or decision makers because they are too biased to individual systems or country-wide perspective. City operator or energy policy designer want to establish energy supply plans for various purposes such as minimizing energy supply costs, minimizing carbon emissions, or maximizing energy efficiency of city and it is essential to simulate several energy supply scenarios within city level before implementing them. Therefore, in this research, both optimizing urban energy system and producing helpful results for urban operator's perspective are conducted. From the next chapter, a long-term simulation and analysis of Naju city's energy mix to meet the Korean government's energy policy goals are described. The methodology for deriving optimal energy mix and simulated results will be presented. And the final results will be compared with KomMod of Fraunhofer ISE, which is conducting joint research, to ensure reliability of the research results.

FORMULATION AND METHODOLOGY OF THE ENERGY MIX OPTIMIZING PROBLEM

Methodological Approach

The optimization algorithm used in this study aims to derive the optimal resource entry plan for energy supply in Smart City. Optimizing is done in perspective of minimizing energy supply costs and determine the capacity and entry timing of each resources. The main algorithm used for the optimization is MILP (Mixed Integer Linear Problem). LP (Linear programming) and Branch and Bound method are used for linear problem and integer problem respectively. In order to use MILP, nonlinear function such as load curve are linearized by using the slope and the intercept of each function. CHP (combined heat and power), renewable resources, and energy storage devices such as ESS and heat storage are also considered in the entry plan. Lastly, the target energy independence rate which is taken as a user input is considered for the optimizing problem.

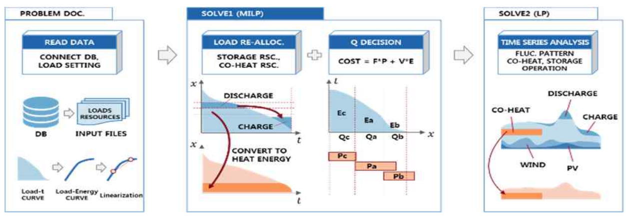


Figure 1. Basic concept of optimizing process

For the optimization solver, commercial solver CPLEX is used. Open source based optimization solver was developed at the beginning of this research, however, because of the limitations in modelling resources such as renewables and heat pump which consumes electricity to generate heat, commercial solver is used as an alternative.

Definition of variables

The set of variables is written in double line letter format. The symbols, definitions and explanations of the set used in the formulation are as follows.

Symbol	Definition	Explanation
$\mathbb{Y}$	$\mathbb{Y} = \{y \mid y \in 1 \dots N^Y\}$	Simulation duration
$\mathbb{W}$	$\mathbb{W} = \{w \mid w \in 1 \dots N^{SW}\}$	# of sampling week
$\mathbb{T}$	$\mathbb{T} = \left\{t \mid t \in 1 \dots \frac{24}{N^{UT}} N^{SD}\right\}$	Time of each week
$\mathbb{L}$	$\mathbb{L} = \{l \mid l \in \mathbb{C}^{time\ series\ load}\}$	Energy demand
$\mathbb{L}^P$	$\mathbb{L}^P = \{l \mid l \in \mathbb{L} \wedge l \in \mathbb{P}^{power}\}$	Electricity demand
$\mathbb{L}^H$	$\mathbb{L}^H = \{l \mid l \in \mathbb{L} \wedge l \in \mathbb{P}^{heat}\}$	Head demand
$\mathbb{R}$	$\mathbb{R} = \{r \mid r \in \mathbb{C}^{resource}\}$	Energy resources
$\mathbb{R}^P$	$\mathbb{R}^P = \{r \mid r \in \mathbb{R} \wedge (r \in \mathbb{P}^{power} \vee r \in \mathbb{P}^{fluctuation})\}$	Electricity resources
$\mathbb{R}^H$	$\mathbb{R}^H = \{r \mid r \in \mathbb{R} \wedge r \in \mathbb{P}^{heat}\}$	Heat resources
$\mathbb{R}^F$	$\mathbb{R}^F = \{r \mid r \in \mathbb{R} \wedge r \in \mathbb{P}^{fluctuation}\}$	Fluctuating resources
$\mathbb{R}^S$	$\mathbb{R}^S = \{r \mid r \in \mathbb{R} \wedge r \in \mathbb{P}^{storage}\}$	Storable resources
$\mathbb{R}^N$	$\mathbb{R}^N = \{r \mid r \in \mathbb{R} \wedge r \notin \mathbb{P}^{fluctuation}\}$	Controllable resources
$\mathbb{R}^G$	$\mathbb{R}^G = \{r \mid r \in \mathbb{R} \wedge r \in \mathbb{P}^{external\_grid}\}$	External grid

Table 1. Definition of sets

Following tables are sets of control variable and input parameters.

Category	Control Variable	Sets	Explanation
Resources	$\bar{U}_{r,y}$	$(r,y) \in \mathbb{R}^F * \mathbb{Y}$	Entering period of fluctuating resource
	$P_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Capacity of energy resource
	$Q_{r,y,w,t}$	$(r,y,w,t) \in \mathbb{R}^N * \mathbb{Y} * \mathbb{W} * \mathbb{T}$	Output of controllable resource
	$Q^S_{r,y,w,t}$	$(r,y,w,t) \in \mathbb{R}^S * \mathbb{Y} * \mathbb{W} * \mathbb{T}$	Consumed energy for charging
	$Q^{CoH}_{r,y,w,t}$	$(r,y,w,t) \in \mathbb{R}^N * \mathbb{Y} * \mathbb{W} * \mathbb{T}$	Energy supplied by CHP
	$Q^{HP}_{r,y,w,t}$	$(r,y,w,t) \in \mathbb{R}^N * \mathbb{Y} * \mathbb{W} * \mathbb{T}$	Electricity consumed by heat pump
	$Q^M_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Energy allocates virtually
	$Q^{SoC}_{r,y,w,t}$	$(r,y,w,t) \in \mathbb{R}^S * \mathbb{Y} * \mathbb{W} * \mathbb{T}$	Energy charged by storage
	C^F_y	$(y) \in \mathbb{Y}$	Fixed cost
	C^V_y	$(y) \in \mathbb{Y}$	Variable cost

Table 2. Control variables

Category	Parameter	Sets	Explanation
Resource	T^{life}_r	$(r) \in \mathbb{R}$	Life time of resource
	Θ_r	$(r) \in \mathbb{R}$	Construction cost
	κ^{max}_r	$(r) \in \mathbb{R}$	Capacity upper limit
	κ^{min}_r	$(r) \in \mathbb{R}$	Capacity lower limit
	σ_r	$(r) \in \mathbb{R}$	Heat rate
	η^S_r	$(r) \in \mathbb{R}^S$	Charging efficiency
	Ξ_r	$(r) \in \mathbb{R}^S$	Heat exchange efficiency
	ε^P_r	$(r) \in \mathbb{R}^P$	Thermoelectric rate
	ζ^P_r	$(r) \in \mathbb{R}^P$	Loss of CHP
	ξ_r	$(r) \in \mathbb{R}$	Emission factor
	γ^F_r	$(r) \in \mathbb{R}^F$	Usage rate of fluctuation resource
	O_r	$(r) \in \mathbb{R}$	Forced Outage Rate
	$F^{o\&m}_r$	$(r) \in \mathbb{R}$	O&M fixed cost
	$V^{o\&m}_r$	$(r) \in \mathbb{R}$	O&M variable cost
	$\mu^{o\&m}_r$	$(r) \in \mathbb{R}$	Operation mileage
	$F_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Fixed cost
	$F^S_{r,y}$	$(r,y) \in \mathbb{R}^S * \mathbb{Y}$	Capacity fixed cost of storage
	$V_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Variable cost
	$V^F_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Fuel variable cost
	$V^{TCO}_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Emission variable cost
	W^{TCO}_r	$(r) \in \mathbb{R}$	Emission per unit energy generation
	$V^{SUB}_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Subsidy
	$V^{SMP}_{r,y}$	$(r,y) \in \mathbb{R}^G * \mathbb{Y}$	SMP
	Ψ_r	$(r) \in \mathbb{R}$	Weight of subsidy
	Υ^{ST}_r	$(r) \in \mathbb{R}$	First available year
	Υ^{ED}_r	$(r) \in \mathbb{R}$	Las available year
	φ^{max}_r	$(r) \in \mathbb{R}$	Usage upper limit
	φ^{min}_r	$(r) \in \mathbb{R}$	Usage lower limit
	$\varkappa^S_r$	$(r) \in \mathbb{R}^S$	Maximum discharging duration

Table 3. Resource input parameter

Category	Parameter	Sets	Explanation
Environment	D_y	$(y) \in \mathbb{Y}$	Discount rate
	$\rho^F_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Fuel cost
	ρ^{SMP}_y	$(y) \in \mathbb{Y}$	SMP
	ρ^{SUB}_y	$(y) \in \mathbb{Y}$	Subsidy
	ρ^{TCO}_y	$(y) \in \mathbb{Y}$	Emission treatment cost
	$\mathcal{H}^{TCO}_y$	$(y) \in \mathbb{Y}$	Emission gas constraints
	$\mathcal{H}^G_y$	$(y) \in \mathbb{Y}$	Energy independency rate constraints
	$\mathcal{H}^F_{r,y}$	$(r,y) \in \mathbb{R} * \mathbb{Y}$	Fuel constraints
	α^{θ}_y	$(y) \in \mathbb{Y}$	Inflation rate of construction
	α^{ρ}_y	$(y) \in \mathbb{Y}$	Inflation rate of fuel cost
	$\alpha^{o\&m}_y$	$(y) \in \mathbb{Y}$	Inflation rate of labor

Table 4. Environmental input parameter

Objective function and recurrence formula

Optimization is performed in terms of minimizing the overall cost, which is sum of fixed cost and variable cost of the simulation. The objective function and recurrence formula that make up the optimization problem are as follows.

$$\min_{(P_{r,y},\ Q_{r,y,w,t})} \sum_{(r,y)}^{\mathbb{R}*\mathbb{Y}} \left(C^F_{r,y} + C^V_{r,y}\right)$$

for all $(r,\ y) \in \mathbb{R} * \mathbb{Y}$:

$$C^F_{r,y} = F_{r,y} \cdot P_{r,y}$$

$$C^V_{r,y} = V_{r,y} \cdot \sum_{w}^{\mathbb{W}} \sum_{t}^{\mathbb{T}} Q_{r,y,w,t}$$

Following equations are recurrence formula of fixed cost and variable cost respectively.

for all $(r,y) \in \mathbb{R}^C * \mathbb{Y}$:

$$F_{r,y} = \left[\frac{\Theta_r}{T^{life}_r} \cdot \min\left(N^Y - y + 1, T^{life}_r\right) \cdot \prod_{\tau=1}^{y} \left(\frac{1}{1+D_{\tau-1}}\right) \cdot\right.$$

$$\prod_{\tau=1}^{y}(1+\alpha_{\tau-1}^{\theta})\Big] + \Big[\sum_{\Gamma=y}^{\min(N^{Y},T_r^{life}+y-1)}\Big(F_r^{o\&m}\cdot \prod_{\tau=1}^{\Gamma}\Big(\frac{1}{1+D_{\tau-1}}\Big)\cdot\prod_{\tau=1}^{\Gamma}(1+\alpha_{\tau-1}^{o\&m})\Big)\Big]$$

$for\ all\ (r,y)\in\mathbb{R}^S*\mathbb{Y}$:

$$F_{r,y}^S = \Big[\frac{\Theta_r^S}{T_r^{life}}\cdot\min(N^Y-y+1,T_r^{life})\cdot\prod_{\tau=1}^{y}\Big(\frac{1}{1+D_{\tau-1}}\Big)\cdot\prod_{\tau=1}^{y}(1+\alpha_{\tau-1}^{\theta})\Big]$$

$for\ all\ (r,y)\in\mathbb{R}*\mathbb{Y}$:

$$V_{r,y}^F=\Big[V_r^{o\&m}\cdot\mu_r^{o\&m}\cdot\prod_{\tau=1}^{y}(1+\alpha_{\tau-1}^{o\&m})+\rho_{r,y}^F\cdot\sigma_r\cdot\prod_{\tau=1}^{y}(1+\alpha_{\tau-1}^{\rho})\Big]\cdot\prod_{\tau=1}^{y}\Big(\frac{1}{1+D_{\tau-1}}\Big)$$

$$W_r^{TCO}=\sigma_r\cdot\xi_r$$

$$V_{r,y}^{TCO}=\rho_{r,y}^{TCO}\cdot W_{r,y}^{TCO}\cdot\prod_{\tau=1}^{y}\Big(\frac{1}{1+D_{\tau-1}}\Big)$$

$$V_{r,y}^{SUB}=\rho_{r,y}^{SUB}\cdot\Psi_r\cdot\prod_{\tau=1}^{y}\Big(\frac{1}{1+D_{\tau-1}}\Big)$$

$for\ all\ (r,y)\in\mathbb{R}^G*\mathbb{Y}$:

$$V_{r,y}^{SMP}=\rho_{r,y}^{SMP}\cdot\prod_{\tau=1}^{y}\Big(\frac{1}{1+D_{\tau-1}}\Big)$$

$for\ all\ (r,y)\in(\mathbb{R}\wedge\{r|r\notin\mathbb{R}^G\})*\mathbb{Y}$:

$$V_{r,y}=V_{r,y}^F+V_{r,y}^{TCO}-V_{r,y}^{SUB}$$

$for\ all\ (r,y)\in\mathbb{R}^G*\mathbb{Y}$:

$$V_{r,y}=V_{r,y}^{SMP}$$

Constraints

Constraints of capacity and usage

The capacity of each resource is determined not to be lower than the minimum capacity limit but not higher than maximum capacity limit. Total capacity of resources is also decided as the sum of the capacities that have entered in the past considering the life period of each resource.

$for\ all\ (r,\ y)\in\mathbb{R}*\mathbb{Y}$:

$$\bar{U}_{r,y}\cdot\kappa_r^{min}\le P_{r,y}\le\bar{U}_{r,y}\cdot\exists$$

$$g_P(r,y)\le\kappa_r^{max}$$

$$\varphi_r^{min}\cdot 24N^{SW}N^{SD}g_P(r,y)\le\sum_r^{\mathbb{W}*\mathbb{T}}(Q_{r,y,w,t})\le\varphi_r^{max}\cdot 24N^{SW}N^{SD}g_P(r,y)$$

$$where,\ g_P(r,y)=\sum_{\tau=\max(1,\ y-T_r^{life}+1)}^{y}(P_{r,\tau})$$

when the resource ‘r’ enters in year ‘y’, the control variable, $\bar{U}_{r,y}$ becomes 1, which makes $P_{r,y}$ bigger than 0.

Constraints of energy balance

Energy balance constraints of each time series demand data are also considered. The energy stored by the storability resource and the power consumed by the heat pump resource to produce heat are considered on the demand side. In addition, the heat energy produced by the CHP is considered on the supply side. Since the fluctuated resource can’t control the output, the energy output is calculated by multiplying the pattern which is analysed in advanced by the capacity of each resource.

$for\ all\ (l,\ y,w,t)\in\mathbb{L}^P*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$L_{l,y,w,t}+\sum_r^{\mathbb{R}^S}Q_{r,y,w,t}^S+\sum_r^{\mathbb{R}}Q_{r,y,w,t}^{HP}=\sum_r^{\mathbb{R}}Q_{r,y,w,t}$$

$for\ all\ (l,\ y,w,t)\in\mathbb{L}^H*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$L_{l,y,w,t}+\sum_r^{\mathbb{R}^S}Q_{r,y,w,t}^S=\sum_r^{\mathbb{R}}Q_{r,y,w,t}+\sum_r^{\mathbb{R}}Q_{r,y,w,t}^{CoH}$$

$for\ all\ (r,\ y,w,t)\in\mathbb{R}^F*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$Q_{r,y,w,t}\le H_{r,y,w,t}\sum_{\tau=\max(1,\ y-T_r^{life}+1)}^{y}(P_{r,\tau})$$

Constraints of storable resource

Energy storage resources are set so that the storage capacity which are calculated by multiplying charging/discharging rate by the charged amount does not exceed the total capacity of resources.

$for\ all\ (r,y,w,t)\in\mathbb{R}^S*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$Q_{r,y,w,t}^{SoC}=Q_{r,y,w,t-1}^{SoC}+\eta_r^SQ_{r,y,w,\tau}^S-\frac{1}{\eta_r^S}Q_{r,y,w,\tau}$$

$$Q_{r,y,w,t}^{SoC}\le g_P(r,y)$$

$$where,\ g_P(r,y)=\sum_{\tau=\max(1,\ y-T_r^{life}+1)}^{y}(P_{r,\tau})$$

Constraints of CHP and heat pump

Since, the CHP supplied the heat energy through the heat exchanger, it is considered by the following constraint equation.

$for\ all\ (r,y,w,t)\in\mathbb{R}^N*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$Q_{r,y,w,t}^{CoH}\le\varepsilon_r^PQ_{r,y,w,t}$$

$$Q_{r,y,w,t}^{HP}=\frac{1}{\Xi_r}Q_{r,y,w,t}$$

Since, most of the CHP use waste heat, the waste heat is set aside if the heat output exceed demand. Heat pump which use inequality constraints, it considers electric-thermal conversion efficiency.

Constraints of energy generation

The optimized problem is defined to produce or store energy per unit of time within a year that does not exceed the total installed capacity. For storable resources, the marginal capacity that can be sent into or out of the grid is reflected in the capacity using the maximum duration value.

$for\ all\ (r,y,w,t)\in\{r|r\in\mathbb{R}\wedge r\notin\mathbb{P}^{storage}\}*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$Q_{r,y,w,t}\le N^{UT}(1-\zeta_r^P)g_P(r,y)$$

$$where,\ g_P(r,y)=\sum_{\tau=\max(1,\ y-T_r^{life}+1)}^{y}(P_{r,\tau})$$

$for\ all\ (r,y,w,t)\in\mathbb{R}^S*\mathbb{Y}*\mathbb{W}*\mathbb{T}$:

$$Q_{r,y,w,t}\le N^{UT}g_P(r,y)\cdot\frac{1}{\varkappa_r^S}$$

$$Q^S_{r,y,w,t} \leq N^{UT} g_P(r,y) \cdot \frac{1}{\varkappa^S_r}$$

$$where\ ,\ g_P(r,y) = \sum\nolimits_{\tau=\max\left(1,\ \ y-T_r^{life}+1\right)}^{y} \left(P_{r,\tau}\right)$$

Constraints of emission gas and fuel

Constraints of emission gas, fuel cost, and energy independence rate are modelled as follows.

$$for\ all\ \ (y) \in \mathbb{Y}:$$

$$\sum\nolimits_{r,w,t}^{\mathbb{R}*\mathbb{W}*\mathbb{T}} \left(Q_{r,y,w,t} W_r^{TCO}\right) \leq \mathcal{H}_y^{TCO}$$

$$for\ all\ \ (r,y) \in \mathbb{R} * \mathbb{Y}:$$

$$\sum\nolimits_{r,w,t}^{\mathbb{R}*\mathbb{W}*\mathbb{T}} \left(Q_{r,y,w,t} \sigma_r\right) \leq \mathcal{H}_{r,y}^{F}$$

$$for\ all\ \ (r,y) \in \mathbb{R}^G * \mathbb{Y}:$$

$$\sum\nolimits_{r}^{\mathbb{W}*\mathbb{T}} \left(Q_{r,y,w,t}\right) \leq \left(1-\mathcal{H}_y^G\right) \sum\nolimits_{l,w,t}^{\mathbb{L}*\mathbb{W}*\mathbb{T}} \left(L_{l,y,w,t}\right)$$

The emission limit is set so that the amount of emission gas of the entire energy resource does not exceed a user defined value. The energy independence rate limits the total energy output to prevent the exceed energy from the external network.

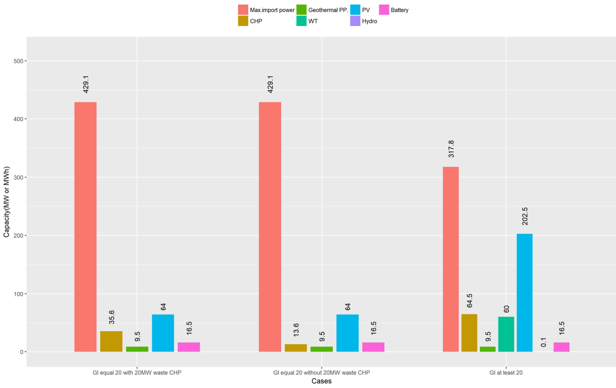
CASE STUDY RESULTS

Overview of case study

In order to verify the validity of this research, a simulation is conducted for the city of Naju, Jeollanam-do, South Korea, where the headquarter of KEPCO is located, and the results were compared with the KomMod of Fraunhofer ISE [5]. The objective of the simulation is to derive optimized energy mix of the Naju. There are 3 cases for simulation: Case 1 is to achieve 20% of energy independence rate with 20MW of waste incineration CHP; Case 2 is to achieve 20% of energy independence rate without 20MW of waste incineration CHP; Case 3 is to achieve as much as energy independence rate. The reason for differentiate case 1 and 2 is that currently the operation of waste incineration CHP is delayed for environmental reasons. Electricity demand and heat demand of Naju are 1898GWh and 292GWh respectively.

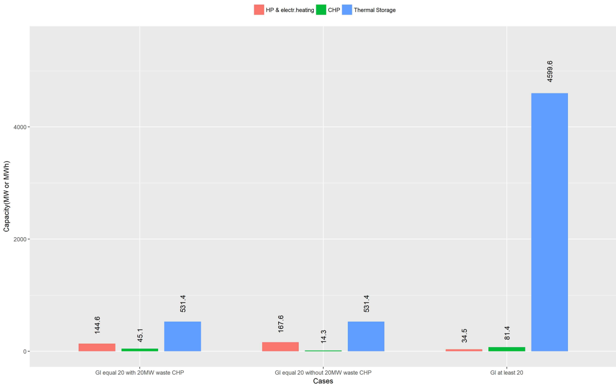
Results of simulation

Capacity of power resource



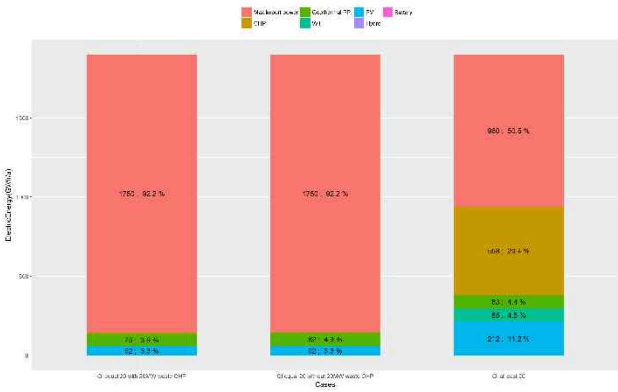
Depending on the presence of the waste incineration CHP, the capacity of each case is much differ. For Case 3, in order to avoid using external input, which is relatively expensive, many renewable resources are installed.

Capacity of heat resource

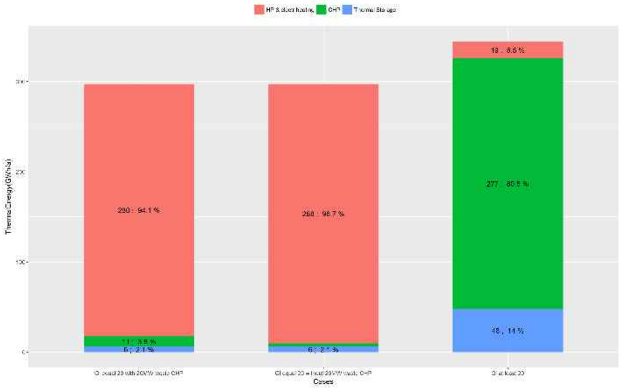


For case 1, CHP covers much of a heat demand, the capacity of other resources is relatively small. However, the case 3 has a considerably high capacity of the heat storage, because the installation cost of the heat storage is cheap, and it is economical to store the heat from CHP in a large amount to assist heat supply in winter.

Energy supply of power resource

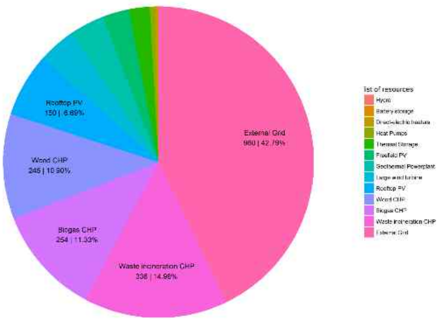


Energy supply of heat resource



Since CHP recycles waste heat, 81% of the heat is supplied by CHP in case 3. The reason why the supply of thermal energy is higher in case 3 than case 1 and 2 is that it includes the charging heat for heat storage.

Energy Independency of case 3



Comparison table

Category	Resource	KEPCO	KomMod	Difference (KEPCO-KomMod)
Energy Independency (%)	Imports from external	43.87	43.61	0.26
	Supplies from internal	56.13	56.39	-0.26
Installed Capacity (MW)	PV	202.5	202.45	0.05
	WT	60.0	60.0	-
	Hydro Power	0.13	0.13	-
	Geothermal PP	9.50	9.50	-
	CHPs	64.45	64.45	-
	Heat pump & electric heater	34.53	35.39	0.14
	ESS	16.5	16.5	-
	Thermal Storage	4599.57	5575.30	-975.73

Table 5. Comparison table

As a result of simulations using same input data, most of the values were the same except for the capacity of the heat storage. Despite the joint project was conducted with Fraunhofer ISE, KomMod's modelling techniques were not used as they were. Therefore, the differences in detailed parameter settings are seem to be the main cause of the error.

CONCLUSIONS AND FUTURE WORK

The present research offers an optimization of the district energy mix for smart city operation. The results of the research would help city operators and decision makers judge by providing time period and capacity of each resource to achieve a certain level of energy independence. In order to ensure the reliability of the research, the results were compared with KomMod of Fraunhofer ISE, which has a reputation in the field, and the results were consistent in most areas. The results of this research will be applied to various smart city projects in Korea in the future, and will be enhanced by applying the latest technologies such as identifying the potential for renewable resources using GIS information.

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