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Methods and tools for community energy planning: A review

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ABSTRACT

High consumption of fossil fuels in urban area leads to environmental pollution and energy shortages, which threaten to reverse human progress. Community energy system planning makes great contributions to reducing fossil energy consumption. This paper focused on the Community Energy Planning (CEP) method at the Community Master Plan (CMP), Community Regulatory Plan (CRP), Community Site Plan (CSP) and Architectural Design (AD) stages. Top-down and bottom-up models for CEP at different stages of community construction were introduced. The present situation and development of research on energy demand forecasting, renewable energy resource assessments and whole community energy system optimization, which are three highly important components of bottom-up models, were introduced. After surveying the methods and tools that have contributed to CEP, the framework of computer tools for community energy system simulation and design was outlined. The functions (particularly focused on the existence of the functions of energy demand prediction, renewable energy resource assessment and whole community energy system optimization) and characteristics of these computer tools for community energy system design (CESD) were listed and compared. One of the current challenges is predicting community energy demand. There is still a shortage of available tools for determining energy-related indictors at the CRP stage. A built Community Energy Consumption data Monitoring and Statistic System (CECMSS) may help to predict a community's secondary energy demand. Ultimately, a framework for a new community energy analysis model that determines energy-related indicators was introduced.

Contents

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1. Introduction

As economic growth and urbanization accelerate in developing countries, the consumption of fossil fuels is increasing rapidly. Sustainable development has attracted much attention as a way to address the problems of energy shortages and environmental deterioration [1–5]. Scholars and urban planners recommend low-carbon cities as the goal of urban development, which means less consumption of fossil fuels, a lower environment impact and a more harmonious social life in the urban setting. One of the hardest tasks is reducing the consumption of fossil fuels in city life.

To reduce the consumption of fossil fuels, actions should be taken on different temporal and spatial scales, such as Community energy planning (CEP). CEP is a part of a city energy development strategy. It assists in optimizing the energy structure and improving the energy system's efficiency. CEP also plays an important role in increasing renewable and sustainable energy utilization. Thus, CEP is necessary for low-carbon city construction.

From surveying the research about CEP, the methods and tools of CEP at different stage are listed in this paper. This paper focuses on the research results about methods and tools for CEP at different stages of community development. In particular, we highlight the bottom-up model for community energy planning. Section 2 introduces the framework of CEP and makes a simple comparison between CEP and traditional primary energy planning (PEP). Sections 3 and 4 summarize the up–down and bottom-up ways to optimize a community energy system. Some frequently used computers tools for community energy system design are discussed in Section 5. Sections 6 and 7 present the survey results and conclusions.

2. CEP redefinition

In this discussion, CEP includes not only the community energy system and facility design but also all energy-related issues in a community, such as a setting energy consumption target, selecting energy resources, and energy conversion technologies evaluation. This chapter makes a comparison between traditional energy planning and CEP. The main contents of CEP at different stages of community development and construction are also introduced.

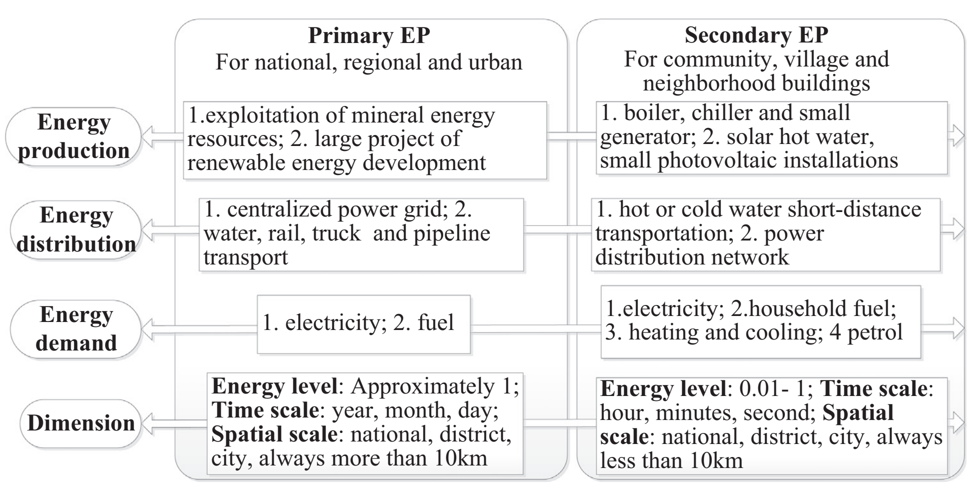

Fig. 1. The comparison between CEP and traditional PEP .

Nomenclature

CEP	community energy planning
PEP	primary energy planning
EP	energy planning
UEP	urban energy planning
CMP	community master plan
CDP	community detailed planning
CRP	community regulatory plan
CSP	community site plan
MP	municipal facilities plan
AD	architectural design
CESD	community energy system design
IRP	integrated renewable and non-renewable energy resource planning
DSM	demand-side management
BREEAM Communities	BRE environmental assessment method and rating system for communities
LEED-ND	the leadership in environmental and energy design for neighborhood development rating system
CASBEE	comprehensive assessment system for built environment efficiency
CECMSS	community energy consumption data monitoring and statistic system
CPM	constraint programming model
IPM	interval programming model

2.1. CEP comparing with traditional PEP

The original definition of community is a social group of any size whose members reside in a specific locality [6]. In this paper, we refer to its geographic meaning and consider community as a unit of the city, which means a small-scale area with mixed land use (preferably less than 10 km^2, but not limited to such areas). The region is divided by streets and roads into more than two blocks. The most important feature is that all the objects belong to one urban detailed planning project, which means all objects can be comprehensively considered and operated by planners. Most urban development projects and new town constructions correspond with the above features. This paper will discuss energy production, distribution and consumption in a small-scale area.

Compared with traditional primary energy planning (PEP), we can regard CEP as secondary energy planning, as the operating object of CEP is secondary energy (the energy can be used directly, such as hot water, chilled water, electricity and household fuels). Concerning the time logic, CEP comes after PEP. Traditional PEP is "supply-side" energy planning, whereas CEP is "demand-side" energy planning. The differences between CEP and traditional PEP are listed in Fig. 1.

2.2. The main content of CEP

The main contents of CEP at different stages of a community development project are rich. The tasks of CEP at the community master planning stage, community detailed plan stage and architectural design stage are summarized in this chapter. The main tasks of CEP at different stages can be illustrated by Fig. 2.

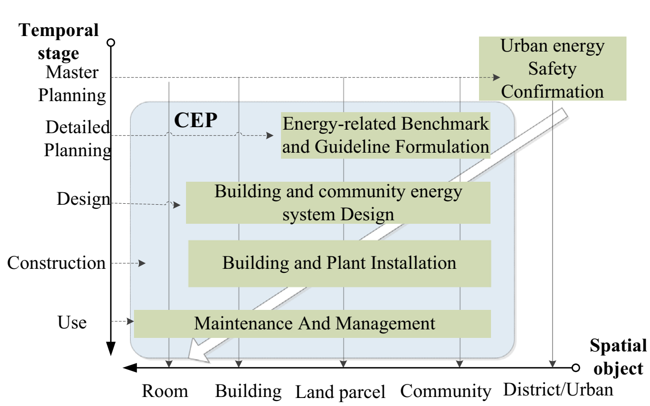

Fig. 2. Main task of CEP at different stage.

2.2.1. Stage 1: Community Master Plan

The main content of a Community Master Plan (CMP) is establishing community goals and aspirations for future development [7,8]. The outcome of a CMP is public policy and principles of development about transportation, utilities, land use, recreation and housing. A CMP typically encompasses large geographical areas, covers a broad range of topics and spans a long time period. The process of CMP includes identifying issues, stating goals, collecting data, preparing the plan, creating implementation plans, evaluating alternatives, adopting the plan, implementing the plan, and monitoring the plan.

CMP covers major aspects of urban/community construction that pertain to energy planning. Many studies are focused on this stage [9]. The main purposes of energy planning at this stage are as follows:

(1) confirm the energy demand and significant energy facility planning;
(2) adjust the relationship between the energy department and other departments as well as the internal energy system departments, such as the growth, scales and structure of different energy types;
(3) perform cost management and investment control for an energy project; and
(4) create guidelines for making energy policy.

2.2.2. Stage 2: Community Detailed Plan

A Community Detailed Plan (CDP) is based on CMP and specific standard set control indicators of land-use and other management requirements or directly makes specific arrangements for facility construction and building design [6,7]. Detailed planning is divided into the Community Regulatory Plan (CRP) and Community Site Plan (CSP).

The main task of energy planning at the CRP stage is to set energy-related goals for the community and land parcels. CEP at the CSP stage is energy infrastructure planning, such as heating the municipal network and heating stations, the power distribution network and the fuel gas network. The planning principle is supply-demand balance, which ignores the inter-conversion between different types of energy sources on the demand side.

2.2.3. Stage 3: Architectural Design

The building energy system design is always followed with architectural appearance design and structural design. The main task of energy engineers in Architectural Design (AD) is to create a comfortable indoor environment by heating ventilation and air

Table 1
Key features of CEP at different temporal stages.

Temporal stage	Spatial object	Implementation strategy	CEP outcomes
CCP	Overall community	Up–down drive, use Standards and statute to promote energy saving	Policy and principle for community energy utilization
CDP			
RCDP	Overall community, Land parcel	Reference analogous project or based on statistical data and technical model calculation result	Energy intensity, Renewable energy percent, investment index
RDDP	Overall community, land parcel	Technical model to optimize energy flow network, energy station location and energy conversion technologies	Energy infrastructure and central/decentralize energy facility construction program
AD	Building, neighborhood building group	Optimization AD, select energy efficiency technologies and plant	Building energy system design paper, building performance design strategy

Table 2
BREEAM Community and LEED-ND rating system on energy.

Assessment issue	Credits	BREEAM community criteria	LEED-ND criteria
Renewable energy contribution	1	10%	5%
	2	15%	12.5%
	3	20%	20%
Fossil energy use		Compare with baseline, CO_2 reduction from 10 to100 percent, credits 1–10 point	ANSI/ASHRAE/IESNA Standard 90.1-2007 as baseline divided into new and retrofit, energy efficacy advanced 10–26% and 5%–22%, get 1–2 point

conditioning (HVAC) systems and lighting and noise control strategies.

2.2.4. Conclusions

Table 1 gives the main purposes, implementation strategies and spatial objects of community energy planning at different temporal stages. Clearly, at different stages of CEP, the planning priorities and operation methods are different.

The core problem of energy planning is to resolve the contradiction between the current supply and current demand, as well as current supply and future demand, which are involved in energy security issues [10,11]. Because of the oil crisis during the 1970s, many governments realized the need to reduce reliance on oil. Thus, laws about municipal facility plans (MP) were created and implemented [12,13]. At present, integrated renewable and non-renewable energy resource planning (IRP) and demand-side management (DSM) have replaced the earlier MP, which focused only on the arrangement of primary energy sources (coal, oil and fuel gas).

3. Top-down method for CEP at CMP and CRP stage

At the CMP and CRP stages, energy planning is usually based on energy policy. It is apparent that CEP is by means of an up-bottom model. A top-down model uses the upper policy to promote the implementation of energy saving measures. Energy policies can be classified as Planning Guidance, Rating System, Indicator System and National or Local Standard System. These standards and guidance are based on the experience accumulated from the practice of many projects and statistic data. In a top-down scheme, planners refer to the information from other communities or cities, and then make a guideline and corresponding measures for the planning area. Thus, this model can be regarded as an “exogenous” method.

3.1. BREEAM Communities

The BRE environmental assessment method and rating system for communities (BREEAM Communities) [14,15] is a certification standard based on the established BREEAM methodology. It is a framework for considering the issues and opportunities affecting sustainability at the earliest stage of the design process for development. This scheme addresses key environmental, social and economic sustainability objectives that have an impact on large-scale development projects. The principles and assessment criteria in this scheme are suitable for a moderate or large mixed-use development area. BREEAM Communities use a rating system to encourage people to reduce energy demand from high-performance construction. It also promotes people to select appropriate technology and use renewable energy to decrease the consumption of fossil fuels in a community.

3.2. LEED-ND

The Congress for New Urbanism and the Natural Resources Defense Council collaborated with the U.S. Green Building Council (USGBC) in creating the Leadership in Environmental and Energy Design (LEED) for Neighborhood Development Rating System (LEED-ND) [16]. Four proposals have been listed in the LEED-ND Reference Guide: (1) reduce building heating, lighting, ventilating and air conditioning energy demand, (2) increase “unused energy” utilization, (3) improve energy efficiency, and (4) use energy recovery system.

3.3. CASBEE for urban development

The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is used for guiding the design of individual buildings in Japan. CASBEE for Urban Development is based on CASBEE, which makes broader assessments and adopts a holistic approach delivered through the urban area [17]. The act of extending the object is based on the idea that taking common environmental measures for buildings within a district can raise the quality of the environment throughout the area, regardless of whether the owners of each individual building are different or same. After selecting items for reducing the load and improving energy system efficiency, a score within a given range will be given to each item.

3.4. Others

Similar to LEED-ND, China formulated some criteria, namely the Standard for sector-specific eco-industrial parks (on trial) (HJ/T 273-2006), the Standard for Sector-integrate Eco-industrial Parks (HJ 274-2009), and the Standard for Venous Industry Based Eco-industrial Parks (On trial) (HJ/T 275-2006) [18–20]. The Technical Assessment Handbook for Ecological Residence of China and other articles have put forward their methods to set energy consumption goals for a community at the earliest planning stage. The rating system in most of the Chinese low-carbon eco-community standards is based on how many energy efficiency technologies are used in the evaluation object. More technology applied means higher marks.

3.5. Conclusion

BREEAM Communities and LEED-ND are widely used for low-carbon eco-community design and evaluation in many countries. For a community energy system, the LEED-ND rating system focuses on an energy consumption target. It encourages engineers to design high-performance buildings and use rational energy technologies to achieve energy goals. BREEAM Communities is based on conditions of the UK. It considers the specific conditions of the project (such as geographic location and climate). It also emphasizes the real effects of the technologies. Both of them have relatively large requests for the energy systems of low-carbon eco-communities. For a large and densely populated urban area, these criteria are difficult to apply well. Without systematic and effective methods to analyze community energy systems at the urban detailed planning stage, it is difficult to set energy consumption goals and put forward effective proposals for following designers and owners. For a detailed analysis of community energy systems, it is necessary to make a systematic analysis about the community energy system.

The BREEAM Community and LEED-ND rating systems have some indexes to evaluate community energy utilization. Some energy-related indexes are listed in Table 2. If the energy demand features and renewable energy resources conditions of the communities are similar, this rating system can be properly used to evaluate and compare energy utilization. These rating systems, however, cannot reflect the differences in energy resources and energy demands between different communities, which is why mechanically applying these rating systems in all communities is unsuitable.

4. Bottom-up model for CEP at CSP and AD stage

The bottom-up model is always used for CEP at the CSP and AD stages. It is a type of technical model that can be divided into a simulation model and dynamic energy system optimization model. Through the description and optimization of the community energy system, the CEP program can be acquired from technical analysis.

4.1. Framework of bottom-up model

Bottom-up models for CEP mainly contain community energy demanding modules, available energy resource modules and energy conversion technologies modules [9]. Each of these three sub-blocks' input and output interfaces are linked by the first and second laws of thermodynamics. In addition to thermodynamics balance, economic and environmental constraints are always integrated in each module. Fig. 3 illustrated the framework of the bottom-up model for CEP. After surveying the models and tools for CEP, this section focuses on load forecasting, available energy resource evaluation and the system optimization method, which are three very important points for CEP.

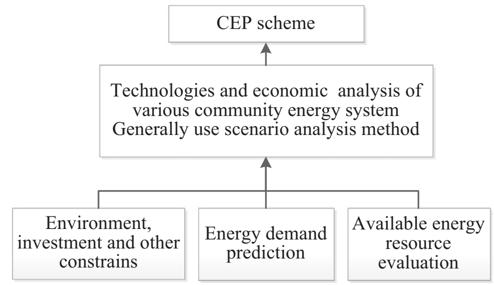

Fig. 3. The framework of bottom-up model for CEP.

4.2. Load forecast

Energy demand in an urban area consists of cooling, heating, electricity and the fuel load. It also can be divided into building, industrial and transportation energy consumption. Industrial and transportation energy consumption merely depends on industrial output products and traffic volume. This part of energy demand can be acquired by transportation and industrial planning. Because building energy consumption is affected by population, construction area, building performance and the habits of residents, it is difficult to predict this part of energy demand precisely. Thus, energy demand forecasting method for building energy consumption has attracted many researchers. Suganthi and Anand Samuel submitted a review of models for demand forecasting in 2012 [21]. Thus, in this chapter, we will not repeat in detail the models and methods for energy demand forecasting, except for research published after 2012. After a brief summary about the methods and tools for demand forecasting, a review about building energy simulation tools will be given.

4.2.1. Statistical regression forecast

The statistical regression prediction method uses history statistical data to predict future energy demand [22–24]. The statistical data contain target variables (load) and independent variables (the variables associated with energy demand). The relationship between energy demand and influencing factors can be expressed by regression equations from the fitting analysis about energy consumption and influencing factors.

The statistical regression prediction method can be divided into time series and key factor forecasting.

The main feature of time series is the collection of historical energy consumption data and arrangement based on time series. Following the statistical analysis about the relations between time and energy consumption data, we can predict future energy demand from the variation tendency. This method is widely used for electricity, fuel and renewable energy consumption prediction. Bargur and Mandel have examined energy consumption and economic growth using trend analysis for Israel [25]. Gonzales et al. have forecasted energy production and consumption in Asturias-Northern Spain [26]. Because of the randomness of key independent variables, this method is unsuitable for the short term and cannot work when forecasting few objects of energy.

Similar to time series forecasting, key factor forecasting depends heavily on historical statistical data or available present statistical data. The difference between time series and key factor forecasting is the independent variables. For an accurate prediction result, analyzing the correlations between all independent variables and energy consumption (dependent variable) is necessary. The key factors can include economic level, population, building area, climate, lifestyle of residents, etc. To analyze the relationship between independent and dependent variables, the simple regression analysis and artificial-intelligence methods are used. Muhammad Tauha Ali, Marwan Mokhtar and Matteo Chiesa estimated the daily electrical cooling load for a city of 800,000 people over 1 year on Abu Dhabi Island. They found that the relationship between the electrical cooling load and weather variables is linear relation when the temperature is above a threshold [27].

To predict building energy demand, Olofsson and Andersson introduced a neural network model to predict long-term energy demand based on short-term measured data [28]. In the summer of 1993, an energy modeling competition, called 'The great energy predictor shoot-out I,' was organized by ASHRAE [29]. The purpose was to evaluate different methods for predicting hourly energy use. Neural networks have a certain capacity to map the linear and non-linear dependencies of the data without using any preconceptions. Neural networks have been used to predict building energy use for both short and long periods, particularly for hourly energy use [30,31]. Other research on building energy load prediction is discussed in the literature [32–35].

4.2.2. Building energy simulation

Building performance simulation is used to predict short-term hour-by-hour thermal/cold demand. It also applies in building energy system analysis. Community-scale energy demand is based on the accumulation of every signal building's energy demand [36]. Some frequently used building performance simulation tools are listed in Table 3.

This type of energy consumption simulation software can calculate building load based on users' input description data and internal standard library [37–40]. Building and energy plant models are two important sections in this type of software.

The software's built-in data library comes from the national standard or ASHRAE design guideline [41]. Users should put in necessary description about buildings and users' activity models. Cooling or heating load is affected by weather, solar conditions, the schedules of people, lighting and equipment, infiltration, heat transfer through the building envelope, ventilation, etc. Load change can be dynamically analyzed based on the energy equilibrium between indoor room air and outdoor air via the building envelope. The weather data for a location consists of hourly values for the outside dry-bulb temperature, the wet-bulb temperature, atmospheric pressure, wind speed and direction, cloud cover, and solar radiation. Weather data are produced by the weather processor for raw weather files, which is provided by the U.S. National Weather Service and other organizations [42,43].

4.2.3. Load index

The energy consumption index of a certain type of buildings can be found based on the energy consumption data from existing buildings. Then, the energy consumption of the planning area can be calculated from the load index and building area according to land use planning. Giuliano Dall' O, Annalisa Galante and Marco Torri classified residential buildings using the data from energy audits for a sample. They developed a model to forecast energy demand in a medium-sized town in the Lombardy region (Italy) [44]. Shuqin Chen performed a statistical analysis of different types of building energy consumption in China and found the quantitative relation between building energy consumption and the critical factor. Based on the building energy consumption index, Mo Chung and Hwa-Choon Park developed a software package for community building energy load forecasting [45,46]. This tool can calculate overall community electricity, heating, cooling, and hot water demands of mixed buildings in Korea based on different types of buildings energy demand indexes, which were formed by the measured data of major cities in Korea.

4.3. Available energy resource assessment

Energy Resource Assessment is used to evaluate the energy supply capacity of energy resources. In most situations, evaluating the environment and economic effect of energy resource utilization is necessary. For the community scale, evaluating renewable and sustainable energy resources is the main task.

Gulden Kokturk and Ayca Tokuc evaluated renewable energy resources using the strengths, weaknesses, opportunities and threats (SWOT) analysis tool for strategic planning for a region on a campus scale. The results showed that the campus was suitable for energy generation from wind, solar and biomass resources [47]. Daniel Schneider, Neven Duic and Zeljko Bogdan surveyed and evaluated the renewable energy resources in the Republic of Croatia and made an appropriate renewable energy utilization technologies map. Wind, hydro, solar photovoltaic, geothermal, and biomass conversion systems were analyzed from technological and economic points of view. They provided the RES cost-supply curves for 2006 and 2010 [48]. Different types of renewable energy available quantity calculation models are introduced in [49–53].

In 2011, Athanasios Angelis-Dimakis, Markus Biberacher and Javier Dominguez submitted a review of methods and tools to evaluate the availability of solar, wind, wave, dry biomass and energy crops, wet biomasses and biogas and geothermal energy resource. They highlighted the challenges of each renewable resource. The available tools to evaluate the use of a mix of different energy sources were also introduced [54].

The renewable energy resources contain

(1) theoretical potential, the theoretical quantity of renewable energy resources that can be used annually;
(2) available capacity, the amount of renewable energy sources that can be used by current technologies (the value is different for different technical routes); and
(3) economic acceptable capacity, the acceptable cost of energy production produced by renewable energy, considering the high cost of some renewable energy utilization.

Total life cycle costs are often used when assessing a renewable energy project. According to the high initial investment, low operating costs, and zero fuel features of the renewable resource

Table 3
Frequently used building performance simulation tools.

Simulation tools	Organization	Availability
DOE-2 (eQUEST)	Lawrence Berkeley National Laboratory	Free to download; http://www.doe2.com/equest/
EnergyPlus	American Department of Energy and Lawrence Berkeley National Laboratory	Free to download; http://www.energyplus.gov
ESP-r	Department of Mechanical Engineering University of Strathclyde	Free to download; http://www.esru.strath.ac.uk/Programs/ESP-r.htm
TRNSYS	The University of Wisconsin Madison	commercial, purchase from http://www.trnsys.com/
Dest	Tsinghua University	Free to download; http://dest.tsinghua.edu.cn

technology in economic evaluation, the use of life-cycle cost is particularly important. Eunnyeong Heo, Jinsoo Kim and Kyung-Jin Boo used the fuzzy analytical hierarchy process (AHP) method to analyze the influencing factors for renewable energy resource. Technical, market-related, economic, environmental, and policy-related criteria were the five factors in this assessment [55].

In addition to economic evaluation, the uncertainty of renewable energy resources has also attracted attention. The scenario analysis, "Monte-Carlo" random simulation and sensitivity analysis methods are often used to analyze the uncertainty of renewable energy resource [56,57].

4.4. Energy supply system optimization

Energy planning is a classical constraint optimization problem. With constraints of investment, energy resource and inhabitant energy demand, we plan to obtain a minimum/maximum target to optimize energy production, distribution and utilization. Linear Program (LP) and Non-Linear Program (NLP) are commonly used to solve this problem. Because it is difficult to find a global optimum solution for this type of problem and this are a large number of possible combinations, many approximation algorithms were developed to attain near optimum solutions (approximation algorithms) [58]. For LP problem, most of the algorithms are based on the Simplex Method. Goncalo Mendes, Christos Ioakimidis and Paulo Ferrao submitted a review of mathematical methods that have been applied to a distribution systems planning area. The developed techniques are now diverse and include Simulated Annealing (SA), Genetic Algorithms (GA), Tabu Search (TS), Evolution Strategies (ES) and other advanced methods such as Artificial Neural Networks (ANN), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) [59].

5. Computer tools for CESD

5.1. EnergyPLAN

EnergyPLAN is a computer tool for hour-by-hour simulation of complete regional or national energy systems including electricity, individual and district heating/cooling, industry and transportation [60,61]. This computer tool focuses on the design and evaluation of sustainable energy systems using renewable and fossil energy together. It is developed by the Department of Development and Planning, Aalborg University, Denmark. The model can be downloaded freely from the official website and used on personal computers.

The main purpose of this model is to assist in the design of national energy planning strategies on the basis of the technical and economic analysis of the consequences of different national energy systems and investments. It has also been applied to local levels, such as towns and/or municipalities [62]. This model emphasizes the synergies of the whole energy system. It has been expanded to include a wide range of technologies and can analyze the interaction between electricity, gas, district heating and cooling grids through various versions. This model is an input/output model. The general inputs are demands, renewable energy sources, energy plant capacities, costs and a number of optional regulation strategies emphasizing import/export and excess electricity production. The outputs are energy balances and resulting annual production, fuel consumption, import/exports and total costs including income from the exchange of electricity [63,64].

5.2. E-GIS

The Environment and energy Geographical Information System (E-GIS) tool can be applied in integrated energy demand forecasts and energy system optimization. It formulates an E-GIS Database for the environmental and energy planning of a city [65]. The E-GIS construction model is composed of an urban GIS integration model, an E-GIS Data Base model and a visualization model.

The urban GIS integration model can integrate urban GIS, visualized urban planning information and the environment and energy Database in 3D space. Based on this visualization information and optimization calculation results, urban planners can provide better planning for a city.

The E-GIS Database model can visualize 2D and 3D information (such as building information, urban climate, land cover information and energy consumption data) for the environmental and energy planning of a city. After the data are collected, they should be processed into a format that can be imported in the GIS data base. After the planning area map is meshed by a certain size grid, the environment and energy information will return to every mesh as feedback. The energy consumption intensity, average temperature and pollutant emission information are visible in the visualization model.

5.3. SUNtool

SUNtool (Sustainable Urban Neighborhood modeling tool) is an early decision making tool for sustainable urban design [66]. It can optimize the layout of neighborhoods buildings (composed by 50–500 buildings), microclimate (temperature, velocity and air pressure) design and sustainable energy plans. The building envelop heat balance equation model and resident occupant stochastic model are used for calculating the heating/cooling and electricity loads of building. The method of load forecasting is similar to building energy performance simulation software (such as DOE-2, EnergyPlus and ESP-r), which can acquire building energy demand from the precise description of a building's envelope and occupants' behavior. An integrated solver can simulate the flows of these resources (energy and matter) in a way sensitive to the urban microclimate, human behavior, synergy between buildings and resources and the presence of district resource management centers.

SUNtool is especially capable of producing urban energy planning guidelines according to the set of energy implications of the urban context on building energy consumption. It is also used to support the sustainable urban planning process, from defining building layouts, forms and facades to planning energy infrastructures.

5.4. Others

Goncalo Mendes, Christos Ioakimidis and Paulo Ferrao submitted a review of tools for integrated community energy system planning and analysis [59]. Connolly, Lund and Mathiesen et al. summarized computer tools for analyzing the integration of renewable energy into various energy systems [67]. Integrated community energy system planning and analysis tools such as HOMER [68], DER-CAM [69–72], EAM [73], MARKAL/TIMES [74], RETScreen [75] and H2RES [76,77] have been compared and summarized. These models and tools can contribute to future community energy system design. The features of these tools were thoroughly explained in the research of Goncalo Mendes and Connolly et al. in [59] and [67], so we will not repeat them in this paper.

Jessen Page, Daniele Basciotti and Olivier Pol introduced a multi-energy model for simulating and optimizing urban energy infrastructure planning [78]. A multi-scale approach was applied to model urban energy networks, especially the backbone of the urban energy infrastructure. Through the detailed simulation of local energy generation, an energy flow model including storage, transport, distribution and demand based on supply-demand balance was built. An optimized urban energy infrastructure network was achieved by solving the constraint equation.

Eugenia, Mehleri, Haralambos Sarimveis and Markatos et al. introduced a mixed-integer programming (MILP) model for the design of distributed energy generation systems satisfying heating and power demand at the level of a small neighborhood [79]. Many other CEP studies have added to decentralized energy planning discussion. Hiremath, Shikha and Ravindranath submitted a review of models and tools for decentralized energy system planning [80]. Thoreau Rory Tooke and Coops summarized remote sensing for urban energy system management and planning [81]. Other research about community energy planning and design is discussed in the literature [82–84].

Atom Mirakyan and RolandDeGuio surveyed the methods and tools for integrated energy planning in cities and territories [85]. They listed the available methods and software resources for the four stages of long-term model-based energy planning processes (preparation and orientation, model design and detailed analysis, prioritization and decision, implementation and monitoring). For stage 1 (preparation and orientation), few methods and tools have been implemented in territories and cities. Nevertheless, stage 1 is very significant within the planning process.

James Keirstead, Mark Jennings and Aruna Sivakumar submitted a review of urban energy system models [86]. They summarized the approaches, challenges and opportunities of these models. This survey was related to seven fields: energy conversion and utilization technologies, building design, urban climate, energy system design, policy assessment, transportation and land use. In that review, they noted that models of urban energy systems play an important role in assessing better design, new policies, and related technologies. They also indicated that future research would confront technology difficulties, the increasing complexity of the urban energy system and other unknown obstacles and challenges.

Albana Kona [87] used Simulated Annealing (SA) to optimize the district heating network under the conditions that heating source space location is settled. Massimiliano Manfren, Paola Caputo and Gaia Costa [88] introduced a framework to embody the main concepts of a local energy management system. They also adopted a multi-criteria perspective to determine optimal solutions to provide energy services through distributed generation. Iraci Miranda Pereira and Eleonora Sadde Assis [89] put forward a method of urban energy management. James Keirstead, Mark Jennings and Aruna Sivakumar [86] introduced the definition, model and tools for urban energy system. They highlighted the characteristic of models and tools in six fields: technology design, building design, urban climate, system design, policy assessment, transportation and land use.

6. Survey results

6.1. CEP method

In this paper, we suppose that CEP contains all the energy management issues within the entire construction period of the project. The CEP methods are different at different stages of community construction.

At the CMP and CRP stages, LEED-ND, BREEAM Communities and other standards or rating system for low-carbon community are widely used. For most countries and cities, there is no national or local standard for CEP. Energy control indicators are rarely contained in outcomes of CRP. LEED-ND is used for community planning universally, which promotes low-carbon community development. With the aid of these ecological community rating systems and design handbooks, urban planners and energy engineers pursue low-carbon community energy system. Energy savings targets and renewable energy percentage in these rating systems are widely quoted as obligatory targets for low-carbon community planning project. Based on these indicators related to energy, planners draw up a community energy utilization plan to regulate community energy system design and equipment installation. This method is a top-down operation model, which is similar to the current urban planning mode and familiar to urban planners. In this pattern, the low carbonization of the community energy system is driven by upper policy. CEP can be blended with current urban planning systems easily, which is why CEP is widely implemented in most community development project.

Sometimes, however, this reference process is difficult because the rating system is not always suitable for the project. CEP currently needs an additional new team. Members of this team include urban planners and energy experts.

At the CSP and AD stages, community energy system analysis/simulation models (RETScreen, H2ERS, EnergyPlan, DER-CAM, EAM, etc.) are extensively used. Engineers and proprietors can use these tools to design distribution or renewable energy systems. They can also select energy efficient technologies and plants with constraint of total investment by these tools. They can use local renewable energy (such as solar energy, wind energy and biomass energy) and fossil fuels (such as natural gas, petrol and coal) to satisfy neighborhood houses' heating, cooling and electricity demands with high energy efficiency and low investment. With the aid of these computer tools, community energy facilities planning and designing can be more efficient and easier.

In recent years, most research achievements have pertained to community energy demand prediction methods, methods of available energy resource evaluation and energy system structure optimization algorithms, including all critical contents of CEP. Computers tools for building energy simulation can output the load of a single building. The sum of the loads of each single building becomes the total energy demand of the community. Statistical regression and load index are always used to predict long-term community energy demand.

6.2. Computer tools for CESD

A comparison of community energy system optimization models listed in Table 4 is based on the following: the function of load

Table 4
The summary of surveyed available CESD tools' function.

	Load forecast	Resource assessment	System optimization	Others
EnergyPLAN	×	Partly	√	CES simulation tools
H2RES	×	Partly	√	Internal use
DER-CAM	×	Partly	√	Access to DER-CAM via web-interface
RETScreen	×	√	√	Widespread and freely use
E-GIS	√	×	Partly	Land-use adjustment
SUNtool	√	Only solar energy	√	Spatial relationship design
HOMER	×	Partly	√	User friendly interface and freely distribution
EAM	Partly	Partly	√	Mixed integer non-linear program model

Annotation: × means without this feature, √ with this function.

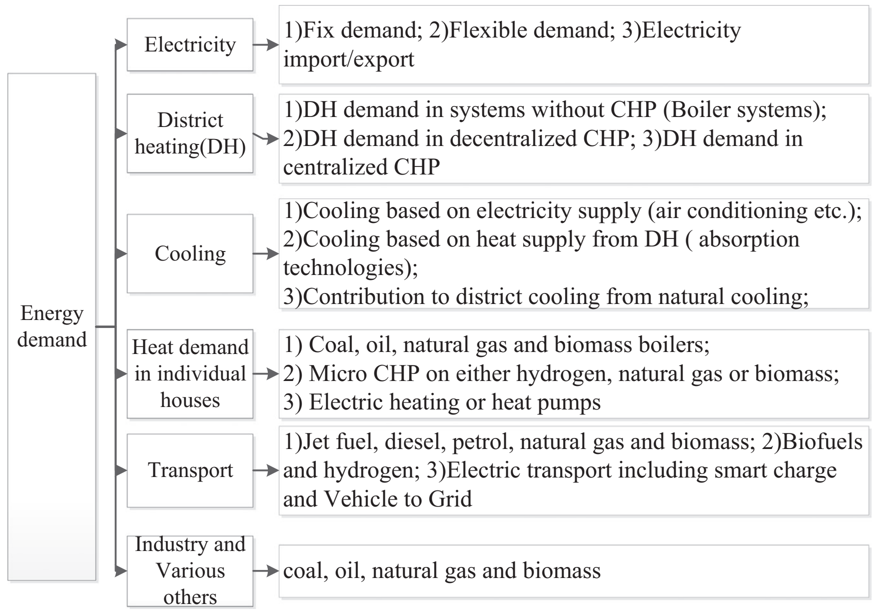

Fig. 4. Energy demand database structure.

forecasts, renewable energy resource evaluation and system optimization. Most of the models cannot predict energy demand or evaluate energy resources, the exceptions being SUNtool and E-GIS with integrated energy simulation modules. At the community comprehensive planning stage, the available technical models are LEAP [90–93] and MARKAL [94–97] for national and large-scale area energy plans. Though RETScreen can be used for community energy planning, it only focuses on renewable and clean energy projects. If RETScreen is used for total community energy system optimization and planning, the user should have a rich experience in energy planning.

From the survey of the models for integrated community energy system planning, it is clear that these technical models focus on optimizing community energy production and distribution. Users input energy demand and available energy resource information (such as price, efficiency and environmental impact), and then the model, integrated with an optimization algorithm and energy conversion technologies database, will output the optimization solution [67,98–99]. Energy demand should be elaborately classified by its exact use. A general classification of energy demand is illustrated by Fig. 4. This data format can meet the requirements for inputting energy demand data in DER-CAM, RETScreen and H2RES.

Integrated community energy system optimization can be regarded as demand-driven optimization. Through the elaborative classification of energy demand, we can obtain an optimal program producing different types of “energy commodities” to meet various energy demands [100,101]. This procedure is illustrated in Fig. 5.

The energy production sub-module describes the process of converting renewable energy (solar, wind, geothermal, biomass, etc.) and fossil energy (natural gas, petrol, coal, etc.) to heat, cold and electricity [102–106]. The energy distribution module describes the process of transferring an energy commodity from the energy production site to the energy demand site. If we regard every energy production site and energy demand site as a node, the transference of energy can be regarded as occurring between different nodes, as illustrated in Fig. 6. We should make a synthesis optimization of energy production schedules and energy transfer schemes. Such an optimization algorithm was discussed in [107–114]. The community energy system will have an optimal structure from this synthesis optimization.

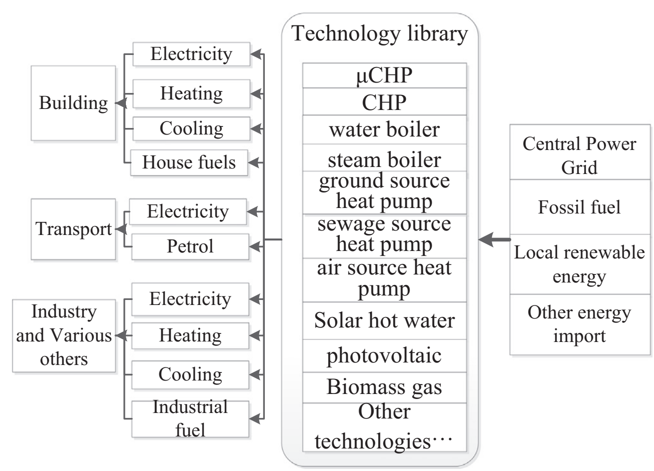

Fig. 5. The structure of current community energy system optimizing model.

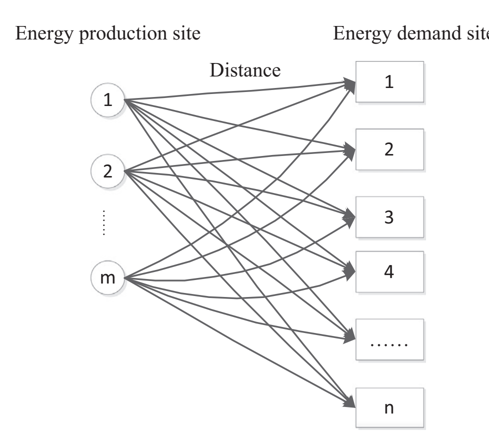

Fig. 6. The schematic of energy commodity transport between different sites.

7. Conclusions

In the last several decades, many studies regarding CEP have been published. Achievements in research regarding energy demand prediction, renewable energy resource evaluation and community energy production-distribution system optimization are also abundant. Many computer tools and models are available for community renewable/distribute energy system design and optimization, the contributions of which to energy efficiency and low-carbon community construction are great. However, challenges for CEP still remain.

7.1. Challenges

7.1.1. Huge uncertainty of energy demand

Jaccard defined the energy system as “the combined processes of acquiring and using energy in a given society or economy” [115], which means energy production, transportation, storage and utilization should be considered together in an analysis of a community energy system. According to Jaccard's definition, integrated community energy system planning can be regarded as demand-side planning. CEP comes from the demand side (classification of inhabitants' energy requirement) and extends to the supply side (converting renewable and fossil energy into different types of energy commodity and then distributing them to users). For an isolated community, the available renewable energy resources and energy conversion efficiency are finite. Minimum carbon emissions can be obtained within a certain demand type. Thus, the ideal energy system scheme depends on the energy demand (containing types and quantities of energy commodities). Figs. 5 and 6 show how energy demand drives energy system planning.

Taking the huge uncertainty of the future development of a community into consideration, it is difficult to forecast community energy demand at the community detailed planning (CDP) stage. Many factors may have an effect on energy demand, such as population, building area, building performance and weather conditions. Without reliable energy demand data, it is unclear whether the planning scheme and target are effective.

7.1.2. Setting energy-related indicators at CRP stage

Urban planning is a mature system to guiding land use. It is also able to guide urban construction and development to some extent. Urban planning results are always regarded as the basis of government policy about the way cities look and grow [116]. At the detailed urban planning stage, the quantitative indexes of land use (such as building density/color/height, green areas coverage rate and urban road density) are explicitly listed in the planning results based on national or local standards. It is improper in CRP to apply energy-related indictors from LEED-ND, BREEAM Communities or others design guideline into every community development project. Such rating systems represent a high level of low-carbon community construction, and many projects are unable to achieve such expectations. As a result, planners would miss the opportunity to guide energy utilization in communities in the absence of rational energy-related indicators in CRP.

At the detailed urban/community planning stage, more detailed land-use planning (such as building types, building area and population) are clearly identified. Based on detailed community planning results, climate and environmental parameters, local available energy resources (including renewable and fossil energy resources), energy-consuming characteristics and project implementation scheduling are all explicit. Acquiring more accurate and suitable energy-related indicators for community at the CRP stage is valuable and possible.

To obtain energy-related indictors for every community, a quantitative analysis of the specific community energy system based on the detailed planning program of this community is necessary.

The community energy system design and analysis tools discussed in Section 6 (such as RETScreen, H2ERS, EnergyPlan, DER-CAM, EAM, etc.) require a given system (or an assumed object) for the optimization process, which means designing the appropriate capacities and mix of a selected set of technologies. Though the tools can choose technology before designing a system, it is difficult and dubious for planners to select appropriate technologies and capacities at the community planning stage [117]. Thus, it is not possible to obtain energy-related indictors from tools, such as DER-CAM and EAM, at the CRP stage.

Traditional energy planning tools, such as LEAP and MARKAL, emphasize energy supply-demand balance. It is more reasonable and reliable to make primary energy exploitation, power plant construction, energy transportation and energy utilization planning schemes based on the in–out energy stream. It is not feasible to use these tools to discuss energy management or small renewable/ distributed energy sources systems on the demand side. It is also not feasible to use them to analyze community energy systems or set energy-related targets.

So far, we have few available tools for the “quantitative analysis” at CRP stage. Without systematic and effective assessment indicators and methods to analyze community energy systems at the detailed urban planning stage, it is difficult for planners to set energy consumption goals and put forward energy effective utilization proposals. Thus, CEP has not been taken into consideration in a large quantity of community development projects, besides traditional urban planning items.

7.2. Possible solutions

7.2.1. Community energy consumption database establishment

Community Energy Consumption data Monitoring and Statistic System (CECMSS) can provide energy consumption information for different types of communities. CECMSS contains an energy consumption information database and energy consumption monitoring device equipped in all of its energy consumption equipment. The energy consumption information database is based on energy consumption data from all of the energy consumption monitoring devices and corresponding land-use information (including geographical features, land development intensity, energy users' features and energy facility information).

In developed countries, the monitoring of building energy consumption is common. The energy consumption databases of various types of buildings have already been established. It is more correct to forecast energy-consuming characteristics of new construction buildings according to these historical energy consumption data. For most developing countries, such as China, Building Energy Consumption Monitoring Systems are rare. CECMSS cannot be popularized in a short time; thus, in China, the community energy consumption database depends only on current energy metering equipment, which can collect energy consumption data from urban energy sectors to build an urban energy consumption information system and database with the aid of Geographic Information Systems (GIS).

Based on the data collected by Community Energy Consumption data Monitoring System, the energy consumption characters of a new community can be obtained from the analysis of historical energy consumption data of similar existing communities from the CECMSS database. Though there are no two same communities, elements included in communities can be similar. We use a building energy consumption database as an example. In the CECMSS database, the primary classification of buildings is

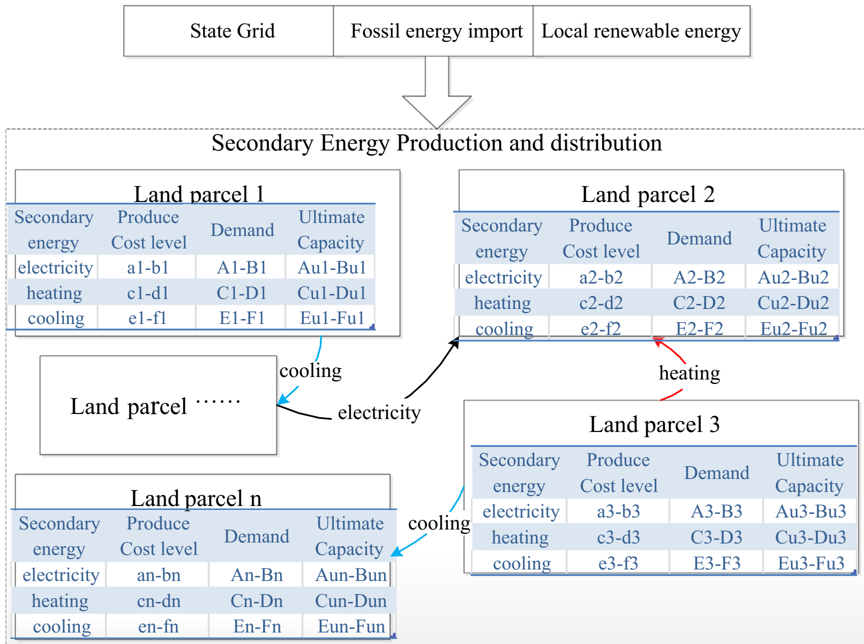

Fig. 7. Diagram of Interval Programming analysis and optimal energy flow.

based on the traditional classification method for commercial, residential, public, retail, hotel, etc. in every climate zones. Cluster analysis according to secondary energy consumption intensity and time-varying characteristics can make further classification of the same building types in the same climate zone. Once enough data have been gathered from the data monitoring device and stored it in the database, the secondary energy consumption intensity of any type of building and corresponding weather data can be acquired. The building types and building area in every land parcel can be confirmed by project documents (these specifications are always acquired from urban planning firm or Urban Design Associates). The scope of the secondary energy requirements of every planned constructed building can be predicted from the reference energy consumption intensity and weather data modification. The secondary energy demand of a land parcel can be obtained by accumulating every building's simultaneous secondary energy demand in one land parcel. When enough energy consumption data, building features and weather data are uploaded to the cloud, precisely predicting future secondary energy demand can reduce error. At same time, GIS coupled with cloud based web communication features enhances the accessibility of historical data.

7.2.2. *Modified model for setting energy-related indicators*

Assume that every land parcel is a single entity that can produce and consume secondary energy. The initial and terminal points of the energy/exergy flow are every land parcel that can produce and consume secondary energy (suppose a large-scale power grid and other secondary energy commodities outside the community in a virtual land parcel). Every land parcel can selectively produce or import a secondary energy commodity to meet its own requirements. For example, a peasant household can choose to produce food itself or purchase food from other household. Purchasing a certain secondary energy commodity from land parcel A, B, C… or producing it itself is determined only by its price; the cheapest available option is the first choice. For a community, we suppose every type of secondary energy is "priced" based on its production cost and transport cost (if production and consumption occur in the same parcel, this value is 0), where "cost" can mean not only currency expended but also fossil energy consumption or environmental costs. Thus, each type of secondary energy has a price (cost can be money, fossil energy resource, carbon emission, etc.).

Based on the above assumptions, a modified transport model was proposed to calculate community energy-related indicators at the CRP stage.

7.2.2.1. Acquiring realizable perfect community energy flow. According to CECMSS data and performance parameters provided by plant manufacturers, the average/rational price of electricity (or other type's secondary energy) produced in every land parcel can be acquired. Every land parcels' space coordinates can be acquired from a GIS database, which is used to calculate the distance between any two land parcels (such as "1" to "*n*" in Fig. 6). If the distance between any two land parcels is determined, the rational secondary energy commodity transport cost between any two different land parcels can be confirmed. Based on the rational production cost and ultimate capacity for every land parcel, the rational transport costs between any two land parcels and the secondary energy demand in every land parcel, a Constraint Programming Model (CPM) can be used to describe and find the minimum total price and energy flow of the overall community. The optimization problem combining production and transportation is a classical transportation problem in graph theory. There are many mature methods for solving this mathematical model to obtain global optimization result. From solving CPM, the perfect/ideal community energy system structure emerges, and relevant energy-related indicators, such as renewable energy contribute, fossil energy consumption ratio and economic efficiency, can be calculated. Changing the definition of "cost", we can acquire the optimal energy/exergy flow with minimum investment, minimum carbon emission, minimum fossil energy consumption, etc.

7.2.2.2. Acquiring interval analysis results. Planning is based on the prediction of the future. Performing a simple analysis of community energy systems based on a precise value of secondary energy demand and the secondary energy production costs of every land parcel is a difficult task in most situations. It is necessary to use the Interval Programming Model (IPM) to create a scenario analysis based on the feasible range of production costs, secondary energy demand and ultimate capacity. At the CRP stage, it is possible to find the rational range of production costs (such as "a1–b1" in Fig. 7), secondary energy demand (such as "A1–B1" in Fig. 7) and ultimate capacity (such as "Au1–Bu1" in Fig. 7) for every land parcel based on community land use planning and the local natural environment (such as available renewable energy resources). From the scenario analysis, the bounds of energy-related indicators can be acquired.

7.2.2.3. Confirming community energy-related indicators. "Perfect energy/exergy flow" acquired from (1) corresponds with an available optimal community energy system at the current technological level and local renewable energy resource endowment. Though this optimal result is not the final planning scheme in most conditions, it is still very valuable as a baseline scenario. From the scenario analysis in (2), planners know a great deal of information about community energy production, distribution and consumption, especially the range of variation of all energy-related indicators. The final energy-related indicators could be a relative value. We use the community renewable energy contribution indicator as an example; it can be calculated and determined by the following equation:

$$\frac{I_{rc}^{\min}}{I_{rc}^{perfect}} \le I_{rc} \le \frac{I_{rc}^{\max}}{I_{rc}^{perfect}}. \tag{1}$$

where I_{rc} is the renewable energy contributes indicator, which can be a certain value or interval, and $I_{rc}^{perfect}$ is the renewable energy, which contributes to a perfect community energy/exergy flow. I_{rc}^{max} and I_{rc}^{min}, meaning the maximum and minimum renewable energy contributes indicators, are acquired during scenario analysis in (2).

Other energy-related indicators, such as the fossil energy consumption ratio and community energy system economic indicators can be calculated like the renewable energy contribute indicator. These indicators reflect the proximity degree of a planning solution to the perfect community energy system scheme and are comparable between different projects.

In the modified model, use cost values represent energy conversion technologies or energy equipment. One cost value may represent many types of energy conversion technologies. The ending points of the energy/exergy flow are energy users distributed in the same community. Compared with the current community energy system optimization model, this modified model sketches up an optimal energy/exergy flow under certain constraints instead of building a community energy system based on a technologies library. The most important difference in this modified model is that every technology is abstract and expressed by a cost value. Cluster analysis of production costs for the same secondary energy commodity simplifies the technical constraint sub-model. This modified model takes only the technical level (reflected by the production cost) and the laws of thermodynamics as constraints to optimize community energy/exergy flows and does not provide a detailed discussion about the combination of specific technical schemes. Information contained in optimal energy/exergy flows can meet the demand of CEP and can also be helpful in the design of community energy systems at the CSP and AD stages.

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