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Graphical Approaches to Facilitate Low Carbon Emissions Economy

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User-friendly approaches or methods that could facilitate communication effectively with policymakers and the public have been a target in developing models for a low carbon emissions economy. Graphical tools offer physical insight and a better understanding of the advantages of the proposed solution or system design, as well as the constraint of the proposed strategies. This article reviews the classical and existing graphical approaches, showing the timeline and trend of some tool series and implementation methods for climate change mitigation. The discussion surrounded the approaches for low carbon buildings and renewable energy development. The future and emerging direction for a low carbon emissions economy are also discussed to tackle the flexibility and reliability issues of the graphical tool for better applicability.

1. Introduction

A low carbon emissions economy is an economic model based on low energy consumption, low pollution, and low emissions. Its core is to improve energy efficiency and achieve a clean energy structure. Graphical tools, which embody the characteristics of the physical inside, can have a huge role in promoting the decision-making of low carbon commissions economy.
Graphical approaches have a long history of development. Recently, there have been some articles that summarise the various applications of graphical approaches. Fan et al. (2020) introduced Pinch Analysis and Process Graph (e.g., P-graph) in the process design and optimisation. Wang et al. (2022) provided a comprehensive survey and analysis of graphical approaches for the applications in cleaner production and sustainability, the effectiveness of material/energy/water consumption and emissions reduction is specifically stressed.
Aiming at promoting low-carbon economy, this paper reviews the graphical approaches that are committed to this purpose, especially highlighting the research results of graphical approaches in low-carbon building and energy fields.

2. Graphical approaches for low-carbon buildings

The building industry is high energy consumption, accounting for 40 % of final energy consumption and 36 % of total CO_2 emissions (Bragolusi and D'Alpaos, 2022). It has great benefit to achieve energy saving in buildings for the low carbon emission development. Graphical approaches, which have visualisation characteristics, have some applications in the building energy reduction field.

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Bragolusi and D'Alpaos (2022) proposed a graphical method that can directly identify building energy renovation project schemes with maximum Net Present Value (NPV) and maximum energy saving. The graphical presentation is shown in Figure 1. The black dots represent buildings' energy retrofit projects (BERPs). ΔEn is the variation in annual energy need, ΔCost is the variation of BERP life cycle cost relative to the BERP. The optimal BERP is the one which graphically shows the greatest negative or smallest positive distance to the reference line.

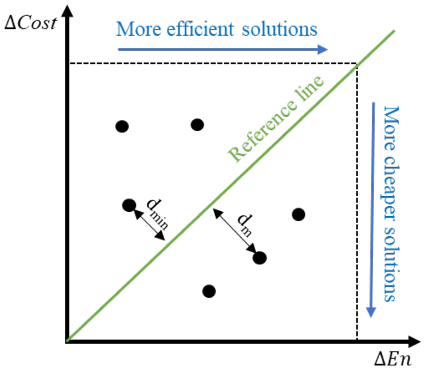

Figure 1: Identification of the optimal solution graphically (adapted from Bragolusi et al. (2022))

To better represent the relationship between energy supply (e.g., power generated by photovoltaic (PV)) and demand in the building, Luthander et al. (2019) proposed an energy matching chart. The principle and case description of the energy matching graph is shown in Figure 2. It was verified in an nZEB in Sweden and performed the power matching information in size and time scales, which provides the reason for the mismatching. The results show that additional battery storage is necessary for the low matching with a single PV system.

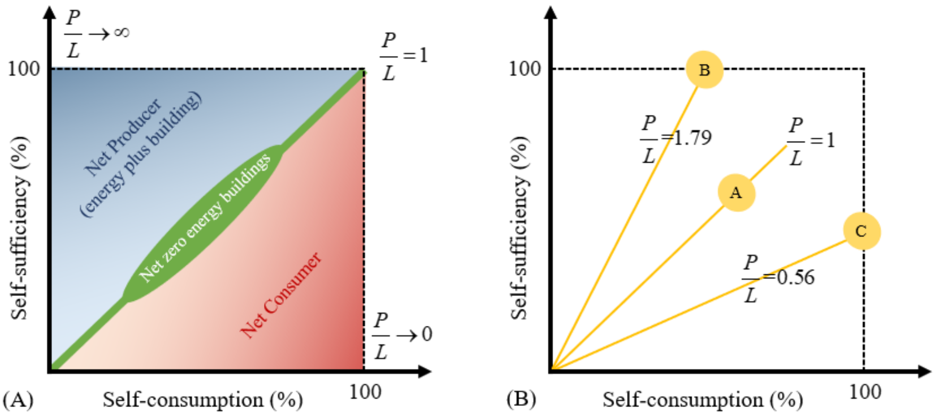

Figure 2: (A) The principles of the Energy matching chart; (B) Example of the Energy matching chart (right) for three systems with different PV electricity production. If P and L remain the same, the self-consumption and self-sufficiency improvements follow a straight line defined by the ratio P/L (adapted from Luthander et al. (2022))

Hosseinnia and Sorin (2021) studied energy-saving schemes in buildings from another perspective. The dynamic flow streams of the building throughout the day were extracted, such as space heating, domestic hot water, renewable solar thermal energy and waste heat (such as grey water). Then the energy supply and demand of the day using graphical analysis were optimised to determine the maximum heat recovery (MHR). The case description is shown in Figure 3. Case studies have shown that by mixing direct/indirect heat recovery (i.e., via thermal energy storage (TES)), integrating heat pump systems, grey water, and solar collectors can reduce thermal utility usage by up to 72 %.

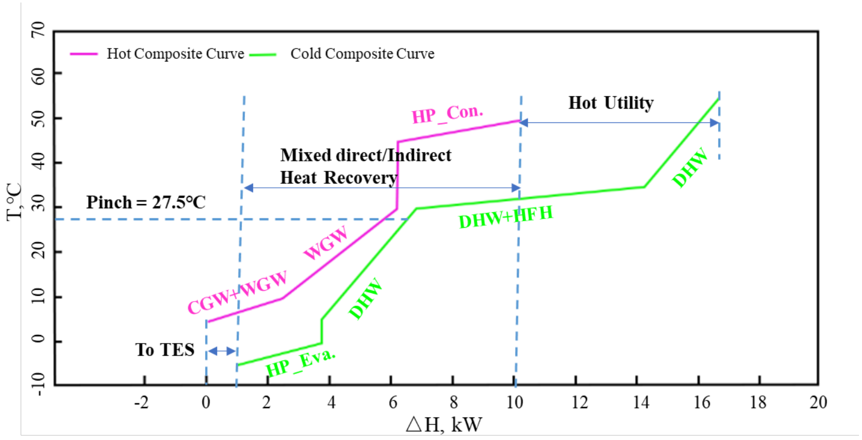

Figure 3: Case description adapted from Hosseinnia and Sorin (2021)

One of the widely applied graphical approaches is the Pinch Analysis. Kong et al. (2022) developed a multi-cycle pinch method for the hybrid power system of renewable and fossil energy in the construction industry, which can achieve target positioning, scheduling optimisation and minimisation of energy demand while meeting the carbon emission limit. An application case in Malaysia illustrates the effectiveness of the method. Malik and Bardhan (2020) established the acceptability index through the Energy Target Pinch Analysis (ETPA) method, which converts the relationship between temperature and energy into the relationship between comfort and acceptability. The Conceptual Analysis Diagram is shown in Figure 4. A Composite Curve similar to the Pinch Method, Source Composite Curve is generated by arranging the processes, i.e., a set of strategies in ascending order of their Degree of Effectiveness (DE), and Sink Composite Curves are generated by plotting Comfort Potential (CP). Select the optimal set of strategies by involving superimposing Source and Sink Composite Curves to identify the Pinch Point(s). The Pinch Point(s) is/are the point(s) of the intersection between the Source and Sink Composite Curves. Analysis of data from 1,267 low-income households in India shows that there is a considerable gap in the acceptance of effective thermal comfort strategies by residents of low-income housing. ETPA optimisation methods contribute to energy efficiency and thermal comfort research by incorporating human selection functions and providing practical solutions for applications.

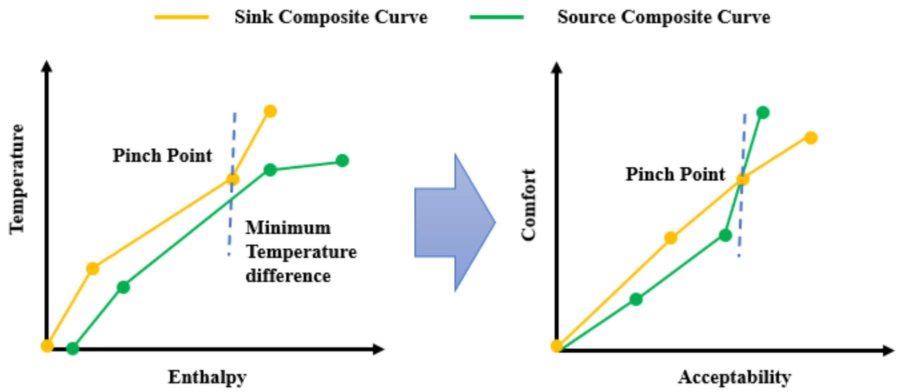

Figure 4: Conceptual analysis diagram adapted from Malik and Bardhan (2020)

The Heat Pinch Analysis is an important tool for decreasing energy usage and pollution emissions in industrial sectors or buildings. At the same time, the fluctuations in the Total Site (TS) system are a serious threat to Thermal Energy Storage (TES) facility. Liew et al. (2014) introduced a novel Total Site Heat Storage Cascade (TS-HSC) Table to display the time-dependent energy flows, including different energy supply and demand in the system, for reducing energy consumption. The method is applied to industrial plants, a hotel and residential areas. The results show that it decreases the external heating devices requirement at the Low-Pressure Steam (LPS) level and also the heating demand at Hot Water (HW) level. Meanwhile, the building cost increases own to the growing storage capacity at the LP level.

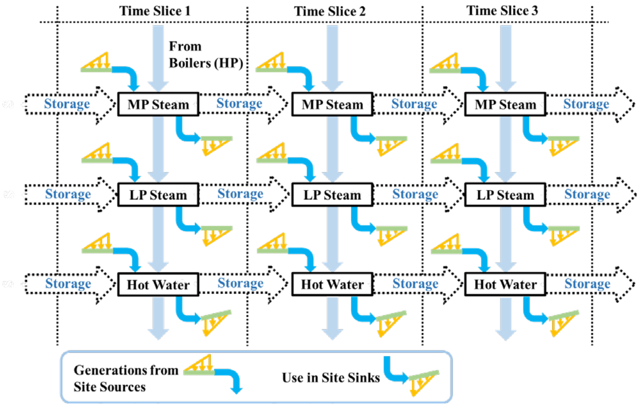

Figure 5: Total Site Heat Cascade

3. Renewable energy development

Traditional energies bring the challenge of net-carbon positive. Besides, renewable energies show the characteristic of high sensitivity to the environment, including geography and climate. Graphical approaches help to promote the decision-making of renewable energy utilisation and development.

The liquid desiccant dehumidification (LDD) system functions greatly in heating, ventilation, and air-conditioning (HVAC) to remove extra moisture and provide healthy air quality within buildings. Low et al. (2021) presented a novel LDD system that integrates a solar thermal system with the regenerator by the Pinch-Based Cascade Analysis (CA). It was featured by an experimentally verified numerical model case with numerous heat supply and demand in batch mode. The results display that the proposed model got an overall system efficiency of 78.8 % under an average daily regeneration heat demand. In addition, it demonstrates the CA approach has a great potential to enable decision-makers to visualise and gain essential information about the continuous energy variation data (Figure 6) and (dis)charging patterns in thermal energy systems.

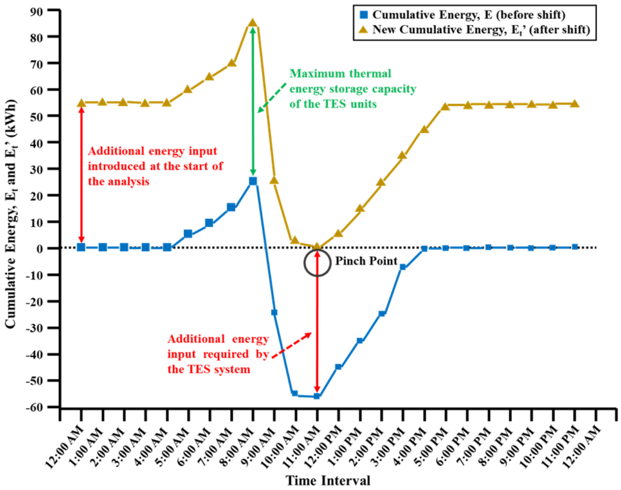

Figure 6: Graphical representation of the cumulative energy before a shift, Et and after shift, Et'

DC Microgrids (DC MGs) have become more and more widely used in the field of integrating various renewable energies own to their high security. However, there are some unexpected mistakes which include insufficient local generation and voltage provision in the islanding process. Eajal et al. (2021) introduced a novel graphical approach based on Bayesian networks (BNs) to realise the reliability analysis of islanded DC MGs. A series of droop-based Distributed Storage (DS) units with droop characteristics are included in the graph for rematching the power supply and the required demand (Figure 7). The proposed method contains numerous reliability indexes to check the influence of high renewables penetration on MG reliability. The accuracy of this BN model was verified by a Monte-Carlo simulation (MCS), and test results show that renewable energies penetration has a great influence on reliability indexes. Besides, it reveals droop control is positive for reliable MG operation in the islanding process.

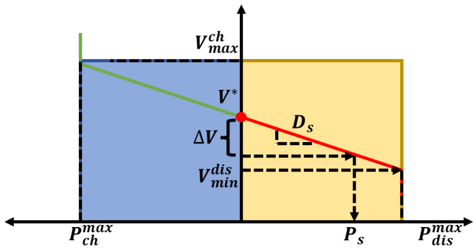

Figure 7: Droop characteristics of a droop-based DS unit (adapted from Eajal et al. (2021))

It is significant to combine the renewable energy apparatus with a DC-DC converter to release unstable power output though the fundamental principle is also needed to be investigated. Sang C.L. (2016) studied the role of the DC-DC converter in energy equipment utilising a graphical and mathematical approach. In their model, the converter distorts the previous 1-V trait curves with D and operates it to control current and voltage. This proposed approach suggests an efficient way to choose the type of converter via comparing the values of peak and operating voltages.

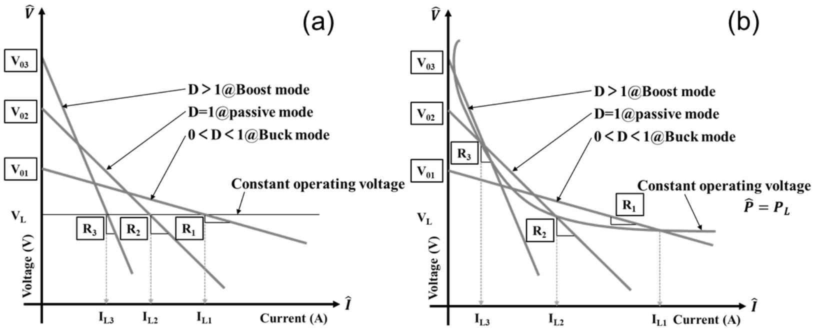

Figure 8: Determining of load currents at (a) constant-voltage mode operation; (b) constant-power operation

Graphical approaches are widely used to solve the mismatch between energy generation and irregular load demand. Elmi et al. (2016) developed an improved power storage technology Power to Gas (PTG) approach based on Pinch Analysis. This novel method builds Power Composite Curves (PCCs) and displays (dis) charging, start and standby times. It also considers the maximum storage capacity and the minimum of outsourced power. It was verified in four farms in French by comparing the two electricity indexes. The results emphasise the need for a more detailed investigation of a reasonable capacity of power generation and the financial feasibility of different energy farms.

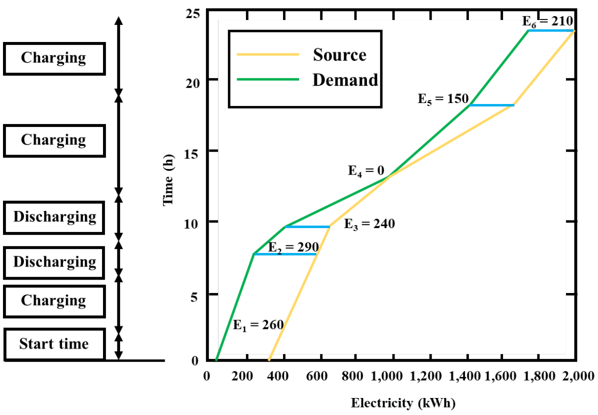

Figure 9: PCC of the illustrative case

Besides those studies, Power Pinch Analysis (Wan Alwi et al., 2012) is an advanced tool that can be applied in Renewable Energy Integration. More interesting applications can be developed based on this concept.

4. Conclusions

This paper reviews and analyses several graphical approaches that contribute to the low carbon economy development in the building and energy fields. The benefits of intuitive approaches are undeniable, especially for effective communication with decision-makers. However, some limitations need to be overcome. There is a trade-off between simplicity for communication and the scope that could be included in the method. It is essential to identify the most representable quality and quantity factor of the particular cases, for example, in Pinch Analysis, to be included in the graphical approach. A wrong selection would have resulted in a less representable solution. Other graphical methods, such as those utilising threshold values or partitioning the area of a graph, are also customised and specifically built for certain situations where a change in one variable will require re-building. Graphical User Interface, which allows a more complicated calculation but serves a similar purpose of being user-friendly even for users with little technical knowledge, also has a limitation of less flexibility where only pre-programmed instructions can be executed. It is unlikely to have a method that fully meets all the criteria. The superiority of one method over another in assessing and improving the low carbon emission economy is better judged by the purpose of the application and the targeted users.
In the future, the graphical tools should be integrated with flexibility and reliability issues to enhance the functions and also the applicability. Especially in the low-carbon emission economy era, the higher flexibility and reliability can directly contribute to safety and thus reduce losses both economically and environmentally.

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