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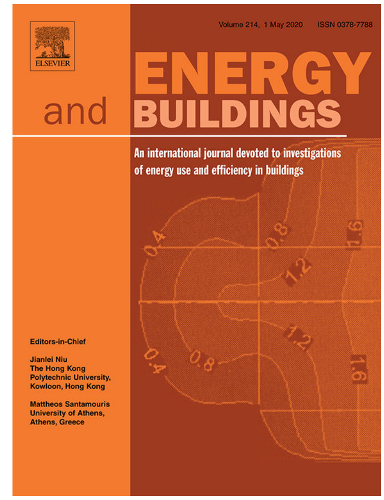

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The Development and Realisation of a Multi-Faceted System for Green Building Planning: A Case in Ningbo Using the Fuzzy Analytical Hierarchy Process

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ABSTRACT

After the Green Building Regulations in the Zhejiang Province was put into effect in May 2016, cities and prefectures in the province were given directives to set their own individual targets for the provision of green buildings. The city of Ningbo decided to use this opportunity to develop a systematic procedure, using Fuzzy Analytical Hierarchy Process (FAHP), to identify which allotments within the municipal area have the greatest potential of delivering green buildings, ensuring the set targets are fair and deliverable.

This paper explains in detail the use of FAHP in the production of the Specific Plans for Green Buildings for the city of Ningbo in the Zhejiang Province of China. This innovative multi-faceted method incorporates the level of development in each of the 3213 land allotments in the municipal area, assessing each one for critical aspects such as environmental potential, local economic development land-use and land prices in order to determine an individual roadmap for the ratio of green buildings to be built in each region within the city. This method incorporates a scientific process, in which Pairwise Comparison Analysis was conducted for the selected criteria and aspects to determine the weighting factors and scores in each case. This allowed planners to rank all allotments in the municipal area in terms of their potential to provide green buildings, and thus make the setting of targets to provide these accordingly. This approach breaks away from the traditional method which relies on simple estimation, which is often unjustified. Over the two years since this method was introduced, the effects had been positive, within all the allotments abiding to the set targets. Other cities and regions in China, such as the provinces of Liaoning and Hebei, have also adopted this process.

The Specific Plans for Green Buildings in Ningbo also include the adoption rate of prefabricated buildings and the mandatory date for when by which new residential buildings should be fully-furnished before they are sold (this is not currently the case in most residential buildings in China). These aspects are also discussed in this paper.

Keywords: Green Building Planning, Fuzzy Analytical Hierarchy Process (FAHP), Green Building, Multi-Faceted System, Specific Plans.

1. INTRODUCTION

As the effects of climate change become progressively apparent, countries across the world are setting up plans to develop low-carbon cities to help mitigate the problem. For example, UK has published the White Paper "Our Future Energy: Creating a Low-Carbon Economy" in 2003 (Department of Trade and Industry, 2003). From the concept of Low-Carbon-Economy, the idea of Low-Carbon Society was developed, and from these two concepts, Chinese scholars put forward the concept of Low-Carbon City, as it was thought that this is the key for the future development for China (Liu, Dai, Dong, & Qi, 2009).There are currently 38 cities in China which have a population of over 3 million inhabitants. If these cities can all become low-carbon and sustainable, then much of the environmental problems in the country could be solved (Cai & Wang, 2010) (Yang & Li, 2013).

At the 18th National Congress in 2012, the Chinese Central Government announced that the development for Green, Low-Carbon Cities would be a key national target (Zhenhua, 2013). Power was given to provincial and municipal governments to develop green and low-carbon cities. For the 13th Five-Year Plan, which was aimed for the period from 2016 to 2020, economically advanced regions such as Shanghai, Jiangsu Province and Zhejiang Province produced strategic plans for the development of green buildings including the overall aim, responsibilities and risk precautions in order to achieve the final aims. Documents such as those from Sun (Sun, Han, & Tang, 2013) and Gao (Gao & Lyu, 2015) provided more specific guidelines for establishing green, low-carbon cities with regards to urban land-use planning, the environment, transport, energy source, water resource and waste management. On the other hand, as the first local legislation for green building in China, the green building legislation of Zhejiang province was promulgated in 2016 (Standing Committee of the 12th People's Congress of Zhejiang Province, 2016). Since then, more and more local green building legislations were published from 2018 to 2019, as the critical roadmap about sustainable society was put on the agenda (Ding, Li, & Meng, 2019). In essence, the push towards a sustainable society in China comes from two fronts: the government as well as the general public. The government has the obligation to resolve current and future energy issues, in order to consolidate a stable future economic model and sustainability; and for the general public, there is an increasing awareness of environmental issues, and an ever-more increasing demand for thermal comfort and energy-efficiency in buildings due to their higher economic freedom from four decades of unprecedented economic growth in China.

This paper will describe and explore the innovative method that the city of Ningbo has used to determine milestones and the rates at which different regions within the city will need to adopt in order to achieve the overall targets set for the city. This method incorporates the use of a scientific procedure, using Fuzzy Analytical Hierarchy Process, together with Pairwise Comparison Analysis to determine the weighting factors and scores for each criterion and each case, in the setting of targets. This breaks away from the traditional method which usually relies on basic estimation, which is often unjustified.

2. DEFINING GREEN BUILDINGS IN CHINA: THE GREEN BUILDING 3-STAR SYSTEM

In China, the Ministry of Housing and Urban-Rural Development developed a Green Building Evaluation Standard (Ding, et al., 2018) to evaluate the level of sustainability for residential and public buildings (i.e. large commercial buildings such as office buildings, hotels and shopping malls). Similar to the US LEED system, this evaluation system, introduced in 2006, is credit-based, and allows developers to choose which credits they want to pursue. In the 2014 version of the standard, “Assessment Standard for Green Building” (GB/T 50378-2014) (Ministry of Housing and Urban-Rural Development, 2014), the evaluation rates buildings in seven categories:

1. Land savings and outdoor environment
2. Energy savings and energy utilisation
3. Water savings and water resource utilisation
4. Material savings and material resource utilisation
5. Indoor environment quality
6. Construction management
7. Operation management

There is an additional category, called “Promotion and Innovation”, which contains strategies that are considered cutting-edge and are harder to implement. These carry bonus points for the evaluation. There are several items that could induce bonus points, for example, using BIM would result in an addition of 2 points, and using carbon emission analysis to minimise emissions would add a further 1 point.

The China green building system grants three levels of ratings: 1-star, 2-star, and 3-star, and is thus named the “Three Star System”. Scores are given to each of the seven categories in the design stage of the building, and once the building is in operation, a new set of evaluations is carried out. The scores are out of 100 for each category, and the overall score, $\sum Q$, is calculated using Equation (1), where Q1 to Q7 are percentage scores for each of the seven categories, and the weightings for each category, ω1 to ω7, are shown in Table 1. Q8 is for bonus scores for preference items.

$$\sum Q = \omega1Q1 + \omega2Q2 + \omega3Q3 + \omega4Q4 + \omega5Q5 + \omega6Q6 + \omega7Q7 + Q8 \quad \text{… Equation (1)}$$

Table 1: Item Requirement for Star-Classification of Green-Building Standard for Residential Buildings

Evaluation Stage	Building Type	Land savings and outdoor environment ω1	Energy savings and energy utilisation ω2	Water savings and water resource utilisation ω3	Material savings and material resource utilisation ω4	Indoor environment quality ω5	Construction management ω6	Operation management ω7
Design Stage	Residential	0.21	0.24	0.20	0.17	0.18	-	-
	Public	0.16	0.28	0.18	0.19	0.19	-	-
Operation Stage	Residential	0.17	0.19	0.16	0.14	0.14	0.10	0.10
	Public	0.13	0.23	0.14	0.15	0.15	0.10	0.10

Buildings must achieve a minimum score of 40% in each category, and overall weighted scores of 50 points, 60 points and 80 points would result in 1-star, 2-star and 3-star certification. As a building moves from the design stage to being in operation, the star level could change due to addition of the evaluation of its construction and operation management.

2.1 SPECIFIC PLANS FOR THE PROVISION OF GREEN BUILDINGS IN THE ZHEJIANG PROVINCE

In China, Specific Plans are promulgated by the government in order to set targets and goals. These plans ensure that the targets and goals are both realistic and achievable, and provide a roadmap for when milestones to be met at different periods. As China continues its development towards a sustainable society, the planning and target-setting of green buildings are essential to implement and realise this intent. For the purpose of gradually increasing the number of green buildings, Specific Plans for Green Buildings are developed by municipal governments to enhance and monitor this process.

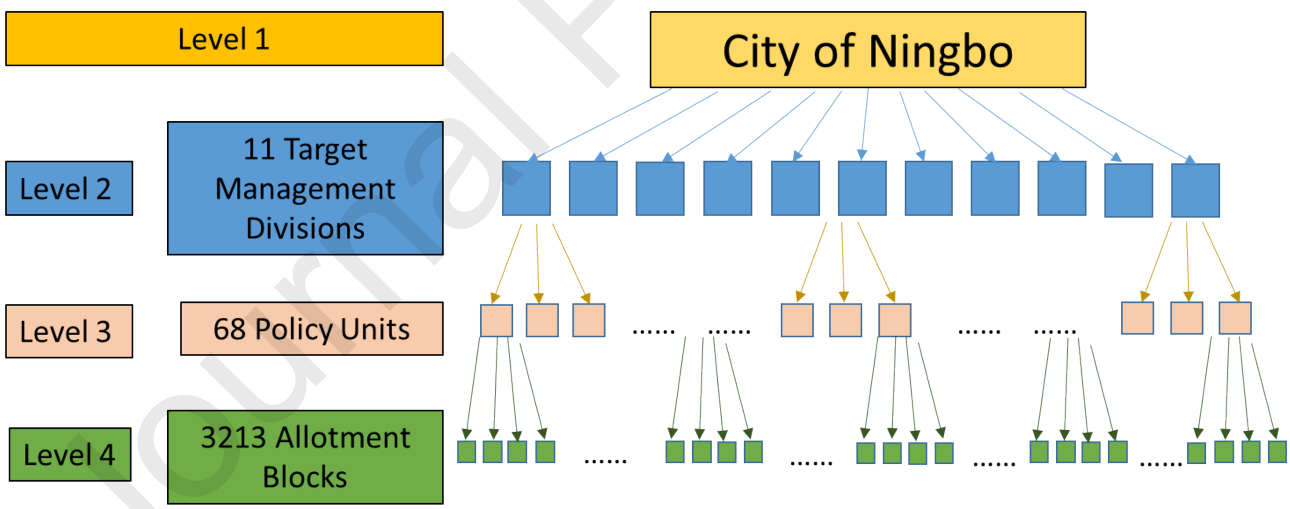
Ningbo is a sub-provincial city in Zhejiang Province, located on the east coast of China, about 150 km south of Shanghai, in the economically developed coastal region of China. A number of sustainable and low-carbon initiatives projects have been undertaken in this city and these have been analysed and presented to an international audience (Chow, Li, & Darkwa, 2013) (Li, Chow, Yao, Zheng, & Zhao, 2019). Some scholars have also explored the effects of urban form on residential energy consumption and presented results for the study area in Ningbo city (Li, Song, & Kaza, 2018).

In July 2018, Zhejiang Provincial Department of Housing and Urban-Rural Development published the “Technical Guidelines to Enhance the Development of Green Buildings in the Specific Plans in Zhejiang Province” (Zhejiang Provincial Department of Housing and Urban-Rural Development, 2018). The aim was to enhance and to implement the already existing national and provincial guidelines and targets for reduction of energy consumption, and the development of green buildings. Under this new guideline, buildings are subject to mandatory requirements set for different regions within the province as well as requirements associated with the building type. In general, natural ventilation, natural daylighting, rain-water collection, waste-heat recovery and solar harvesting are all parts of considerations that will need to be demonstrated for new and refurbishment projects. There is a special mention of public buildings, which are seen by the government as pioneering and exemplary for sustainable buildings.

According to this guideline, all cities and regions in the Zhejiang province should develop their own “Specific Plan for Green Buildings”. These specific plans should be based on relative laws, background review (such as climate and terrain), adequate field research (such as energy consumption, economic and region developments) and the developments of green building techniques and building prefabrication techniques. New buildings and existing buildings are to be considered separately. Besides, for the convenient management of each block in the cities, this guideline proposed a four-layer structure: "City” level, "Target Management Division (TMD)" level, "Policy Unit (PU)" level and “Allotment Blocks (AB)” level. The City level is the highest level that may contain several TMDs. Each TMD is partitioned by boundaries of sub-regions in a city and comprises of a number of PUs. Many ABs with similar regulatory clauses have been consolidated into a typical PU. For each PU, regulatory clauses and guiding clauses are set to regulate and guide building constructions and retrofitting projects, and the clauses include green building ratio, prefabrication building ratio, furbished ratio and renewable energy ratio. As the lowest level, the ABs also inherit some key attributes (e.g. ratio of green spaces) from the urban regulatory detailed planning. However, for the specific plan for green buildings, the four most important regulatory clauses of the ABs to be met by specific future periods are: 1. the rank of green building to be built on this allotment, 2. whether a building built in the block is prefabricated, 3. if the building is residential, whether it needs to be fully-furnished (this is not currently the case in most residential buildings in China) and 4. the required water-capture ratio of total annual runoff volume. All these regulatory clauses must be determined before the ABs are listed for sale. Guiding clauses are indices related to passive and positive green building technologies, and these are flexible depending on local conditions such as economic development, energy supplement and climate. With guiding clauses, designers can choose from various green building technologies and indices.

With the requirements of this guideline, and using local conditions such as social, economic and green building developments, Ningbo has developed its own specific plan for green buildings in 2018 (Ningbo Government's Housing and Rural Development Committee, 2018). Ningbo's specific plan inherits the four-layer structure proposed by the provincial guideline for management convenience. In the urban district of Ningbo City, the four-layer structure includes 1 City Level (Ningbo City, level 1), 11 TMDs (level 2) and 68 PUs (level 3), and 3213 ABs (level 4), as shown in Figure 1.

Figure 1: The four-layer structure for implementing green-building planning in the city of Ningbo



The specific plan details planning for a period of 8 years from 2018 to 2025, including a short-term plan from 2018 to 2020 and a long-term plan from 2021 to 2025. The plan provides the legal basis and building standards that must be in compliance with building constructions in Ningbo. New buildings and existing buildings are to be treated separately. For new buildings, regulatory indices such as the green building rank, indications of prefabrication and fully-furbished requirement, together with water-capture ratio of total annual runoff volume are proposed to restrict and improve building design. For existing buildings, targets for energy efficiency in retrofitted buildings for each year from 2018 to 2025 are proposed.

3. ESTABLISHING OVERALL TARGETS FOR GREEN BUILDINGS

Other researchers (Zeng, 2018) (Zhu, 2017) have described the work and method used in establishing green building planning targets for the cities of Wenzhou and Jinhua in the Zhejiang Province. As with other cities and regions in China, the systems for target-setting used in these cities were unjustified and relied on traditional estimation. Since March 2018, around 55 counties and 11 prefectural-level cities in the province have released their specific plans for green buildings, and at the same time, as a prefectural-level city, Ningbo also published the aforementioned document, “Specific Plan for Green Buildings in Ningbo (2018-2025)" (Ningbo Government’s Housing and Rural Development Committee, 2018). The method used here is different from the traditional description of green buildings development in previous documents such as those addressed in the 13th Five-Year Plan, in that it uses a systematic approach to calculate the actual requirement for each county and district, while satisfying the overall targets set for the specific plans for the city. This systematic approach was envisaged to provide a stronger rationale for the process of target-setting, with the aim of making these targets more realistic and achievable.

3.1. ESTABLISHING THE OVERALL TARGET FOR NINGBO

Before actual targets are set for the city of Ningbo, targets for cities in China with similar climate and economic development along the Yangtze River Delta, such as Shanghai, Nanjing, Hangzhou and Suzhou, were studied and compared with the situation in Ningbo. An expert panel studied and discussed how close to these targets Ningbo can feasibly follow. According to the “Green Building Regulations of the Zhejiang Province” (Standing Committee of the 12th People's Congress of Zhejiang Province, 2016), up to the end of 2016, 18 building projects achieved Green Building status in Ningbo, covering a total area of 1,543,740m^2. There are six 1-star rated projects (covering an area of 292,590m^2), four 2-star rated projects (covering an area of 219,150m^2), and eight 3-star rated projects (covering an area of 1,032,000m^2). At present, the percentage of building area with 2-star or above in Ningbo is 23%, and for 3-star the percentage is 8%. For neighbouring cities, the targets of constructed areas achieving 2-star or above by 2020 are shown in Table 2. After comparing the potential and current status of Ningbo, the target was set for 50%, of which 9.5% needs to be rated 3-star. As from 2021-2025, this number will rise to 60%, of which 13.5% will be 3-star, as shown in Table 3.

Table 2: Targets for building areas to be Green Building star-rated by 2020 for cities along the Yangtze River Delta

City	Shanghai	Nanjing	Suzhou	Hangzhou
Green building ratio (Green Star 2 and above)	70%	60%	60%	55%

Table 3: Targets for building areas to be Green Building star-rated for Ningbo

		2018	2019	2020	2021 - 2025
Green building ratio	Ratio of buildings of Green Star 2 and above	30%		50%	60%
	Ratio of buildings of Green Star 3	4.5%		9.5%	14.5%

3.1.1. ADDITIONAL TARGETS FOR PREFABRICATED CONSTRUCTION, REFURBISHED RESIDENTIAL BUILDINGS AND WATER RUN-OFF

As well as targets for the number of building projects to achieve certain levels of the Green Building standard, the government of Ningbo also takes the opportunity to incorporate other sustainability measures to enhance the city to becoming low-carbon. Such measures include establishing targets for the ratio of buildings constructed using prefabrication techniques, the number of residential buildings to be fully-furnished before they are sold, so that a minimum standard of insulation etc. can be ensured, and also the water run-off as part of the requirement of establishing a sponge-city (Sponge-cities are cities in China where the problem of waterlogging, which has been a major issue in many cities, are eased by means of providing a more permeable built surface (Xia, et al., 2017). These targets were consulted and decided by an expert panel after studying a number of reports and using their knowledge of local feasibility for each case. Table 4 shows the overall targets set out for Ningbo.

Table 4: Other regulatory indices for Ningbo City

	2018	2019	2020	2021 - 2025
Fully-furnished residential buildings when sold or let out (Only central district zone of the city)	100%			
Integrated Renewable Energy ratio	12%	15%		20%
Prefabrication building ratio	20%	35%		60%
Water-Capture ratio of annual runoff volume	75%			/

According to statistical analysis, if the short-term plan targets are fulfilled by 2020, there will be a reduction of 250,000 tons of CO_2 emission, 86.1 million kWh electricity will also be saved, and building energy efficiency will be improved by 11% (Ningbo Government's Housing and Rural Development Committee, 2018).

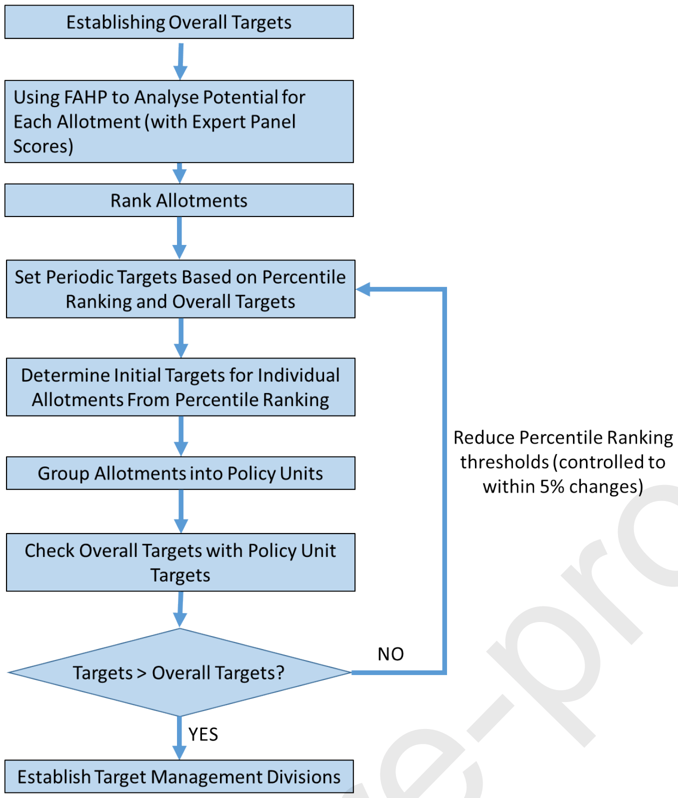
3.2. ESTABLISHING SPECIFIC REQUIREMENTS TO ACHIEVE OVERALL TARGET

In order to ensure that the set targets could be met feasibly within the set time-scale, the next stage is to divide and allocate specific targets for each TMD and PU in Ningbo City in order to implement these overall targets for the Specific Plan. In previous cases, both in Ningbo and the rest of China, the setting of specific targets was done without any scientific procedure and guidance. The method described in the following section uses a Fuzzy Analytical Hierarchy Process (FAHP), to identify allotment areas that are more ready to provide higher levels of green buildings. The criteria are based on objective technical factors such as the economical use of the land and the ratio of green area that there is, together with social influence factors such as the investment entity and the use of the building in the allotment. The weighting for these factors were calculated using a Pairwise Comparison Analysis of all the factors at different levels. The following sections will describe in detail how the targets were set, and more importantly how these were set for PUs and TMDs.

4. TECHNICAL ROADMAP FOR REALISING THE SPECIAL PLANNING FOR GREEN BUILDINGS

In order to implement the overall targets efficiently, it is paramount to have a thorough understanding of the potential of each site to achieve sustainability. For the municipality of Ningbo, an expert panel was set up to evaluate the potential of each allotment in terms of its abilities from the level of development, wealth in terms of GDP to the level of involvement by the local government. The basic roadmap for the planning of green buildings for Ningbo is shown in Figure 2.

Figure 2: Basic Roadmap for Implementing Targets for Target Management Divisions.



4.1. USING THE FUZZY ANALYTIC HIERARCHY PROCESS (FAHP) FOR THE FEASIBILITY EVALUATION OF GREEN BUILDING PLANNING

A Fuzzy Analytic Hierarchy Process (FAHP) (Mikhailov & Tsvetinov, 2004) (Kahraman, Kaya, & Cebi, 2009) was used to decide the weighted-importance of criteria such as the economical use of land (volume rate) and the current ratio of green area to determine the potential capacity of the allotment to develop future green buildings. These criteria were established from the Assessment Method for Green Buildings - GB/T 50378 (Cheng & Ye, 2012) (Lei, 2015), and the weighting system established by the expert panel was developed using a Pairwise Comparison Analysis.

4.1.1. PAIRWISE COMPARISON ANALYSIS FOR ESTABLISHING WEIGHTINGS FOR VARIOUS SELECTED CRITERIA

The selected expert panel consisted of professors in local universities in Ningbo, together with chief practitioners in the local construction industry. The criteria used for establishing targets were first separated into two group; B1: the objective technical factors, and B2: the social influence factors. Using Pairwise Comparison Analysis, the weighting between B1 and B2 was first established. Subsequently, the weightings for individual factors within each group were calculated using the same method.

A matrix with all the criteria under consideration was first set up, the expert panel then decides the relevant importance between different pairs, using guidelines given in Table 5.

Table 5: Guidelines for expert panel for scoring in Pairwise Comparison Analysis

Score	Guiding Criteria
1	When both factors in the comparison have the same importance.
3	When the factor in the left-sided column is slightly more important than the one it is compared against.
5	When the factor in the left-sided column is obviously more important than the one it is compared against.
7	When the factor in the left-sided column is significantly more important than the one it is compared against.
9	When the factor in the left-sided column is extremely more important than the one it is compared against.
2, 4, 6, 8	These scores can be given if the comparison of importance is considered to be between above criteria.
Inverse scores	Inverse scores (i.e. 3 => 1/3) are given for factors considered less important in the comparison.

After the completion of the matrix, the geometric mean of the scores of each criterion was calculated (i.e. taking the nth root of the product of all the scores, whereby n is the number of total criteria in the matrix). The total sum of all the geometric means was then calculated, and the weighting for each criterion is the ratio of its geometric mean over the sum of all geometric means. Table 6 shows the process for establishing the weighting factor between B1 and B2, and Table 7 shows the more complex matrix for establishing the individual weighting factors within B2.

Table 6: Pairwise Comparison Matrix for establishing weighting factors between B1 and B2

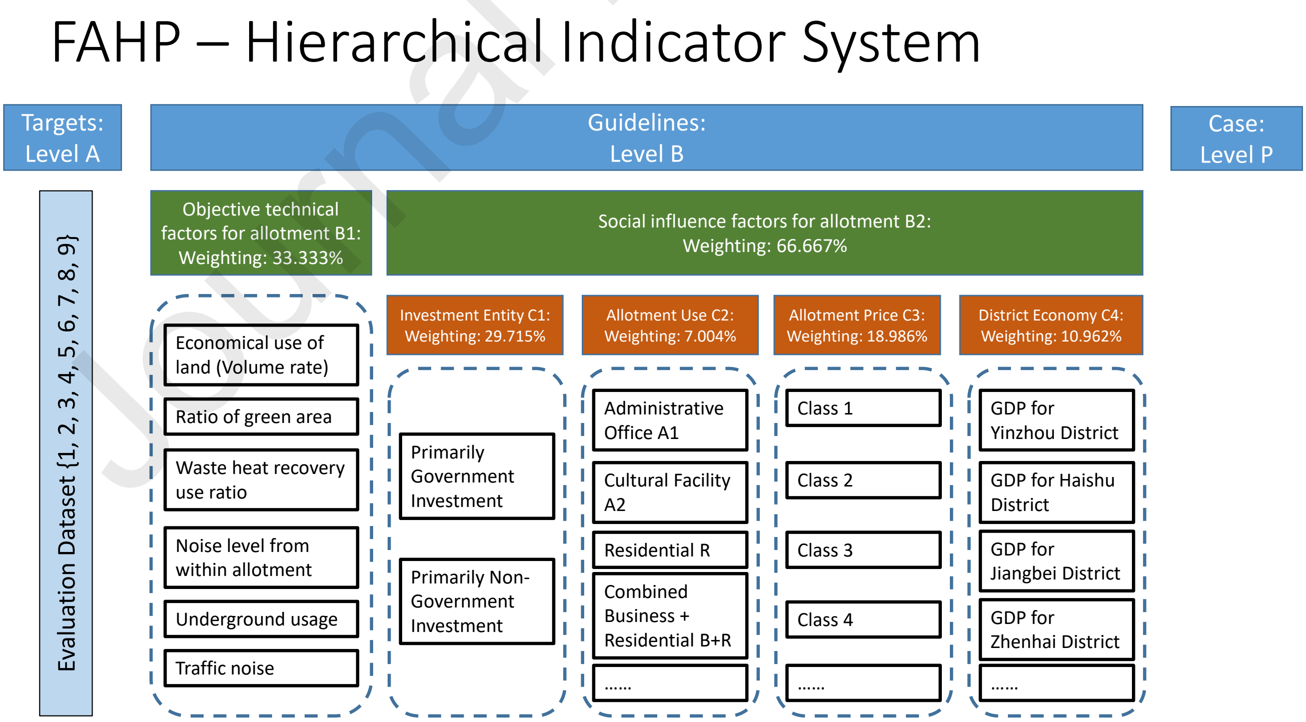
	Matrix		**Product**	**Product ^0.5**	**Sum of (Product^0.5)**	**Weighting**
	B1	B2				
B1	1	1/2	0.500	0.707	2.121	**0.333**
B2	2	1	2.000	1.414	2.121	**0.667**

Table 7: Pairwise Comparison Matrix for establishing weighting factors at for criteria under B2

	Investment Entity C1	Allotment Use C2	Allotment Price C3	District Economy C4	Product	Geometric Mean	Sum of GM	Weighting
Investment Entity C1	1	3	2	3	18.000	2.060	4.621	**44.572%**
Allotment Use C2	1/3	1	1/3	1/2	0.056	0.485		**10.506%**
Allotment Price C3	1/2	3	1	2	3.000	1.316		**28.479%**
District Economy C4	1/3	2	1/2	1	0.333	0.760		**16.443%**

The values calculated in Table 7 are the weighting factors within B2. To calculate the overall weighting factor, these were multiplied by the weighting factor for B2, 66.667%. For example, for Category C1, Investment Entity, the overall individual weighting factor would be 66.667% x 44.572% = 29.715%. The whole hierarchical indicator system used for determining the potential for an allotment to develop green buildings, including the individual weighting factors, is shown in Figure 3.

Figure 3: The Hierarchical Indicator System for the Fuzzy Analytic Hierarchy Process (FAHP) used to determine the potential of an allotment for green building adoption



4.1.2. SCORING SYSTEM FOR ALLOTMENTS IN NINGBO (LEVEL P)

Integer scores from 1 to 9 are given for the set of objective technical factors for each allotment. The factors in this section are all based on factual information available from databases such as economical use of land and noise levels, with the highest value given a score of 9 and the lowest one a score of 1. The levels are then divided equally to provide ranges for each possible score.

The social influence factors involve opinions from the panel of experts who collectively decide the score for each allotment based on their knowledge of the allotment. Again, Pairwise Comparison Analysis was used for the different options under each criterion. However, this time, instead of calculating a weighting factor for each option, the highest and lowest scoring options were given a score of 9 and 1 respectively. The difference between these extreme values were then divided equally by 8 to establish boundaries for integer scores between 1 and 9. The following factors were considered under level P:

(1) Investment Entity: This is a differentiation between government / government-funded buildings and those with no government investment. As the government has a strong obligation to provide green buildings, these will have a score of 9, while non-government investment buildings will receive a score of 1 in this category.

(2) Allotment Use: This is based on how the land is used and the difficulty for achieving a high level of green building for different building types is considered. Pairwise Comparison Analysis was conducted to evaluate different allotment uses to determine integer scores between 1 and 9. Examples of these scores are shown in Table 8.

(3) Allotment Price: This relates to the land price of the allotment. The higher it is, the more responsibility and more potential it has to provide green buildings. Again, integer scores of 1 to 9 are given in this category.

(4) District Economy: Like the case with allotment price, if the district has a high GDP (based on its tertiary industries), then its ability to provide green buildings is higher. Integer scores from 1 to 9 are given in this category.

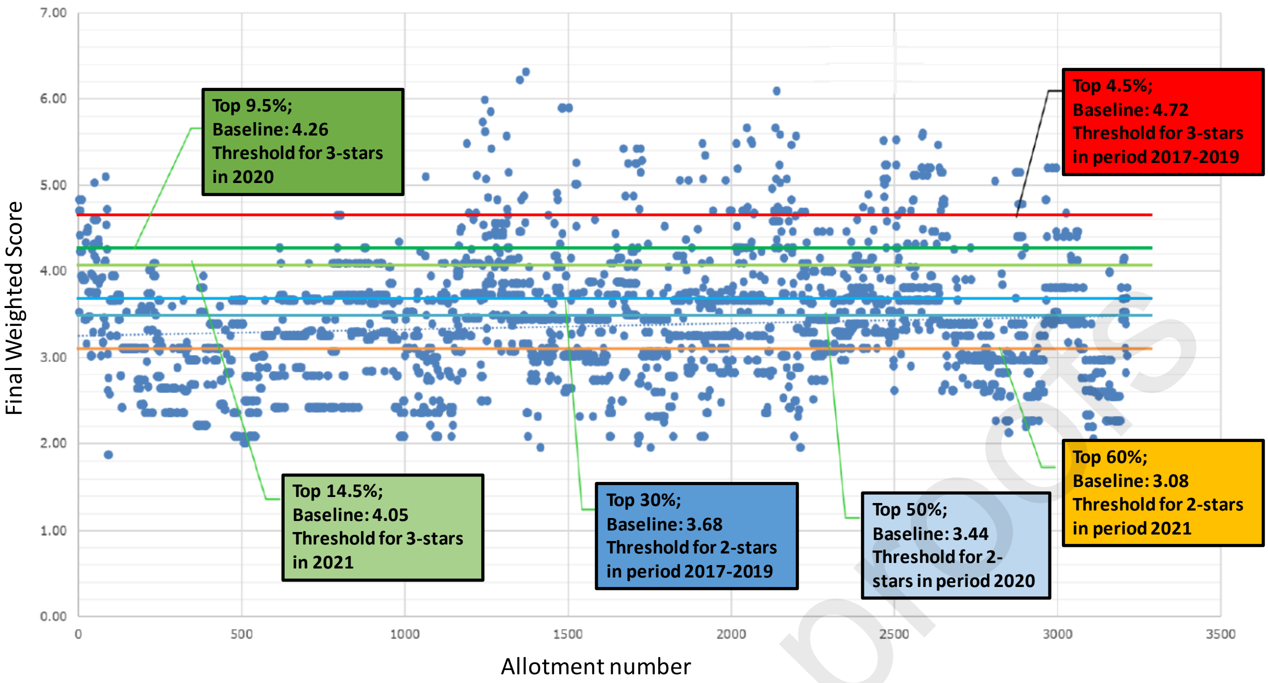
Table 8: Assigned Scores for Various Allotment Uses deriving from Pairwise Comparison Analysis

Allotment Use	Assigned Score
Administrative Office	8
Cultural Facilities	7
Educational Research	4
Specialised Middle School	4
Scientific Research	2
Sports Facilities	1
Medical and Health	5
Social Welfare	1
Religious Facilities	1
Commercial Services Facilities	3
Commercial Facilities	3
Business Facilities	8
Recreational Facilities	1
Mixed Commercial and Residential Use (Type 1)	6
Mixed Commercial and Residential Use (Type 2)	7
Residential Use	9
Transportational Hub	4
Industrial Use	2
Urban Constructional Use	2

4.2. DECIDING ON LEVELS FOR GREEN BUILDING DEVELOPMENT

Using the weighting method developed by the panel of experts, a weighted overall score was calculated for each allotment in the municipal city of Ningbo. The higher the score, the more feasible it is to develop a higher level of green building standard in that allotment. This information is extremely useful in the planning of developing green buildings in the city. As specific targets for the city have already been set (for example, 50% or more of built-up land should have buildings at a 2-star level or more), a ranking of feasibility / ability of each allotment can help establish the actual requirement for the development of green buildings for each individual allotment. The results for individual allotments and the thresholds for various requirements are shown in Figure 4.

Figure 4: Final Weighted Scores for all 3213 allotments in Ningbo



4.3. COMBINING ALLOTMENTS INTO POLICY UNITS

Since the allotment sizes are too small to set as implementable PUs, neighbouring allotments that have similar characteristics in terms of green building and prefabricated building requirements are grouped together, using existing main administrative boundaries, main roads, railway lines or rivers as borders for these PUs.

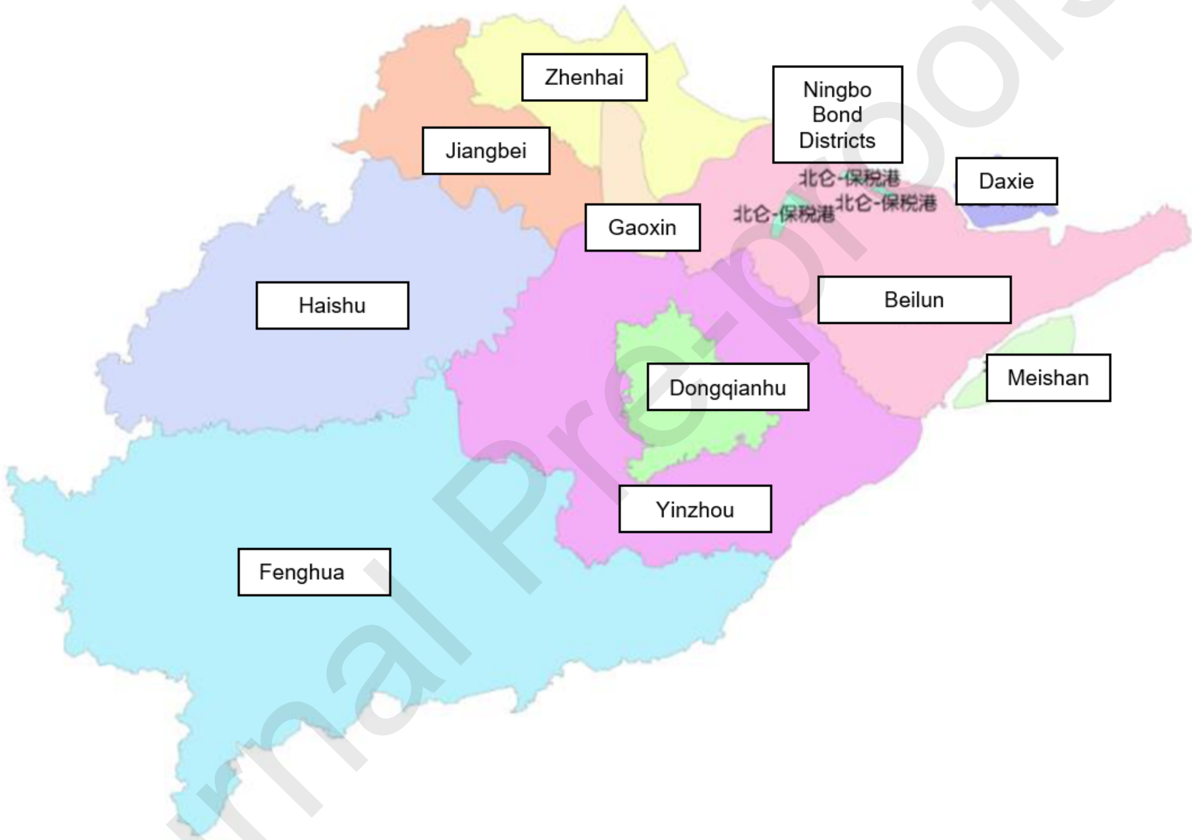
4.3.1. TARGETS FOR POLICY UNITS

The regrouping of allotments into larger PUs may raise or lower the overall requirement for the development of green buildings for some of the land. Hence another calculation is required post-regrouping to see if the specific target for the city is still being achieved. If the final outcome is higher or equal to the original target, it would be fine. However, if it has become lower, then the baselines set out in section 4.2 will need to be re-adjusted, and the process repeated to obtain new individual targets until the overall target can be met. The final overall target should be no more 5% of the original target, to ensure that the target is realistic and achievable.

4.4. GROUPING POLICY UNITS INTO TARGET MANAGEMENT DIVISIONS

In order to manage the implementation of the policies, one or several PUs are further grouped into TMDs. These are roughly based according to existing county / region borders, but the overall targets for each division is calculated based on the targets calculated earlier for the PUs that lie within it. The geographical locations of these TMD regions are shown in figure 5. It should be noted that TMDs are used mainly for government administrative purposes, as with the exception of the bond districts, these are very much the same as the existing administrative regions of the city of Ningbo. The implementation of achieving the targets of green buildings are delivered on a PU / AB level.

Figure 5: Map for the 11 Target Management Divisions in Ningbo



5. FINAL URBAN GREENING TARGETS FOR NINGBO

After using the rigorous process described in the previous sections, which links back to the initial targets set out by the overall urban master plan for Ningbo (2006-2020), individual targets for each TMD were produced.

5.1. TARGETS FOR STAR-LEVELS OF GREEN BUILDINGS

Taking the requirement for each PU into account, the targets for the ratio of green-star rated buildings required for each TMD region were calculated. These are shown in Table 9.

Table 9: Targets for the ratio of Green-Star Rated buildings in each Target Management Division in Ningbo

Name of Target Management Division (TMD) Region		Haishu	Jiangbei	Zhenhai	Yinzhou	Gaoxin	Dongqianhu	Beilun	Meishan Bond District	Daxie Development Zone	Ningbo Bond District	Fenghua
Number of Policy Units in each TMD		8	10	6	13	4	2	11	3	2	1	8
2018-2019	1-star	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	2-star	30%	35%	25%	30%	50%	25%	25%	25%	20%	0%	25%
	3-star	7%	7%	3%	6%	6%	3%	3%	3%	0%	0%	3%
2020	1-star	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	2-star	50%	55%	40%	55%	90%	40%	45%	45%	35%	30%	45%
	3-star	10%	11%	8%	11%	18%	8%	9%	9%	7%	6%	9%
2021-2025	1-star	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	2-star	60%	70%	50%	65%	100%	50%	55%	55%	45%	35%	55%
	3-star	14%	16%	11%	15%	20%	12%	13%	13%	10%	9%	13%

5.2. TARGETS FOR PERCENTAGE OF AREA FOR FULLY REFURBISHED RESIDENTIAL BUILDINGS AND PREFABRICATED BUILDINGS

As from 2018, all new residential buildings built in Ningbo will need to be fully furnished before they are sold or let out. The targets for the percentage of buildings to be prefabricated for each individual TMD region is show in Table 10.

Table 10: Targets for the ratio of prefabricated buildings and fully-furbished residential buildings in each Target Management Division in Ningbo

Target Management Division Serial Number		330200-01	330200-02	330200-03	330200-04	330200-05	330200-06	330200-07	330200-08	330200-09	330200-10	330200-11
Name of TMD region		Haishu	Jiangbei	Zhenhai	Yinzhou	Gaoxin	Dongqianhu	Beilun	Meishan Bond District	Daxie Development Zone	Ningbo Bond District	Fenghua
2018	Area ratio of prefab bldgs	65%	80%	35%	40%	100%	20%	20%	10%	40%	100%	30%
	Full refurbishing for resi bldgs	All new residential buildings in designated area to be fully refurbished when sold or let out.										
2019 - 2020	Area ratio of prefab bldgs	100%	100%	100%	100%	100%	100%	100%	20%	100%	100%	100%
	Full refurbishing for resi bldgs	All new residential buildings in designated area to be fully refurbished when sold or let out.										
2021 - 2025	Area ratio of prefab bldgs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Full refurbishing for resi bldgs	All new residential buildings to be fully refurbished when sold or let out.										

5.3. IMPLEMENTING TARGETS USING POLICY UNITS

As described earlier, the overall targets for each TMD provide each district government with their aims. However, the actual implementation of the policies will be conducted from a PU / AB level. Maps with clear indication of each Allotment Block were produced for each of the 68 PUs, detailing the level to be reached for each AB. An example for one of the PUs in the Haishu District (330200-01-001) is shown in figure 6. There is clear information regarding the boundary of each Policy Unit, as well as the land-use for each AB within the PU, and details of the level of green-star building that needs to be achieved by different building types (e.g. educational buildings, healthcare buildings or office buildings) at different periods in the table in the bottom-right corner. The details of this are translated in the English version shown in Figure 7. The actual implementation of achieving the set targets will be based on the use of these PU maps. Information from these maps are also available from the website: ljgh.zhuneng.cn. In an increasingly digital age, this enhances the usability and transparency of all the requirements, and also provides easy access to this information to anyone who has an interest in it.

When an allotment goes into procedure for tender, auction or listing, these targets will need to be met by the purchaser of the land. The unambiguous nature of this system would make it clear to all stake-holders to what standard needs to be delivered, and by which time-scale.

Figure 6: Example of individual Policy Unit map for implementation of targets

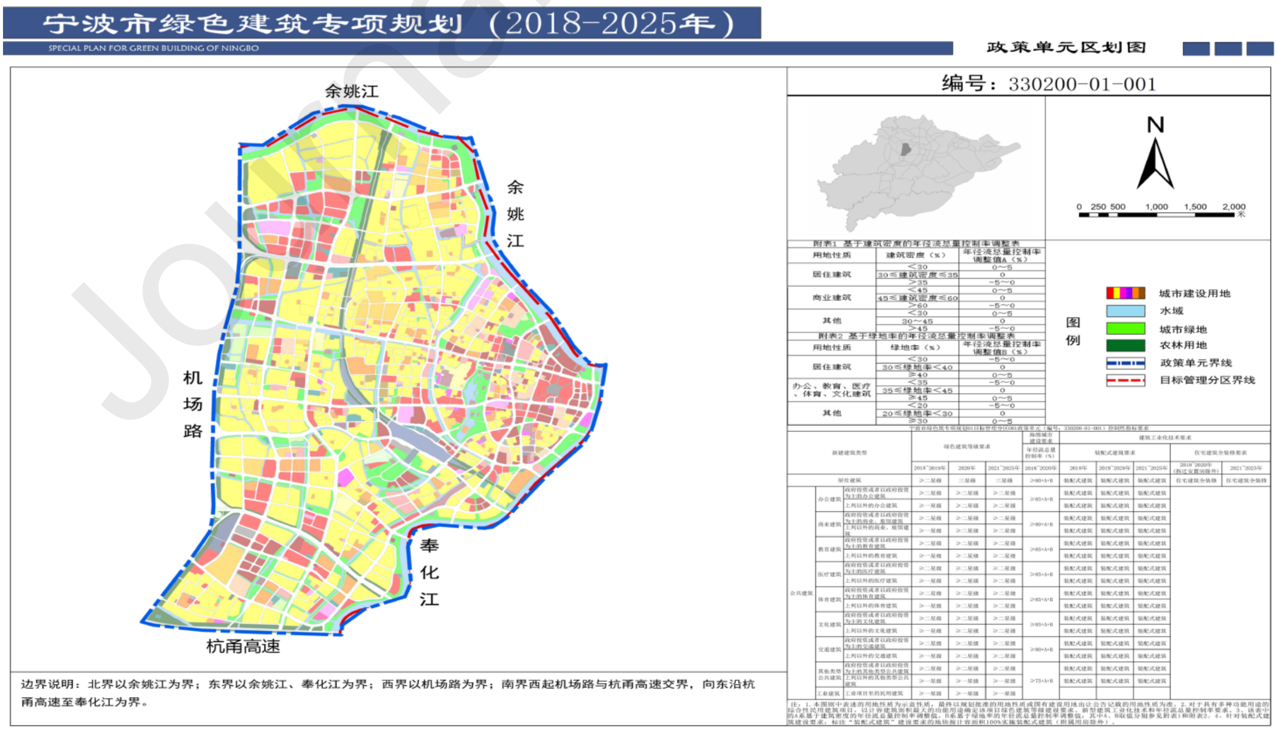


Figure 7: English version of the detailed requirement table for different types of buildings within the Policy Unit 330200-01-001 (For the annual run-off rates, A and B are factors to address the density of buildings (for A) and green area ratio (for B) of the allotment. These factors have values between -5 and +5.

Type of new buildings			Requirement for green building level			Requirement for Sponge City	Requirement for Industrialisation of Construction				
						Annual Run-Off Rate	Pre-fabrication Requirement (Yes / No)			Fully-Furbished Residential Buildings Requirement (Yes / No)	
			2018-2019	2020	2021-2025	2018 - 2020	2018-2019	2020	2021-2025	2018-2020 (excluding resettlement buildings from demolition)	2021-2025
Residential Buildings			≥ 2-star	3-star	3-star	≥ 80+A+B	Yes	Yes	Yes	Yes	Yes
Public Buildings	Office Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 85+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Commercial Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 80+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Educational Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 85+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Health Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 85+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Sports Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 85+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Cultural Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 85+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Transportation Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 80+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Other Public Buildings	Gov Funded	≥ 2-star	≥ 2-star	≥ 2-star	≥ 75+A+B	Yes	Yes	Yes		
		Non-gov funded	≥ 1-star	≥ 2-star	≥ 2-star		Yes	Yes	Yes		
	Industrial Buildings	Civil buildings in industrial projects	≥ 1-star	≥ 1-star	≥ 1-star						

5.3.1. POSSIBLE SHORT-COMINGS OF IMPLEMENTING TARGETS

Although there are many advantages to adopting this systematic method for setting and implementing green-building targets in a city, there are also several possible short-comings that need to be noted. One of these is that the use of land for any allotment could be changed by the government, and this would change the score and ultimately the real ranking of the allotment. Also, actual transfers of land often happen much later than the dates set in the plans for land transfers, making targets set for an earlier period irrelevant. All these suggest that this system will need to be constantly evaluated and improvements made. For example, since the outbreak of Covid-19 in China, plans have now been made to include health and wellbeing targets such as levels of Indoor Air Quality (IAQ) for the buildings.

6. CONCLUSION

The development of low-carbon cities is essential for the sustainable development across the world, and this is even more important for a fast-growing economic society like China. The implementation of feasible targets is important for ensuring low-carbon cities could be realised. This paper describes and explains the process of establishing reasonable milestone targets for the municipal area of Ningbo in the Zhejiang province of China. Unlike other regions in China, where these low-carbon targets are often set without any systematic procedure ((Ding, Li, & Meng, 2019), (Gao & Lyu, 2015), (Li Z. , 2018))), Ningbo developed a systematic way by including first evaluating a realistic overall target for the municipal area by comparing it with neighbouring cities and the targets they have set. Then, a panel of building experts was set up to first establish a weighting system to be used for the Fuzzy Analytic Hierarchy Process (FAHP), and then each of the 3213 allotments were individually assessed and scores were given. These were then ranked to see which category of green-building standard they need to achieve by certain milestones, and similar allotments were grouped into 68 PUs. Adjustments were made if the final target from the PUs fell short of the overall target set for the city of Ningbo. The final targets for the PUs were then grouped again according to existing region boundaries to establish targets for the 11 TMDs.

This system provides a logical process for establishing targets for the number of green-buildings in a city, and as shown in the case of Ningbo, can work in conjunction with other sustainable targets such as the percentage of prefabricated buildings and water run-off rates (which is part of the development of Sponge Cities). With the inherent flexibility of this approach, it is envisaged that this method will be able to adapt to changes to requirements in the future, to both include more criteria and more targets.

Other regions in China, such as Hebei Province (Standing Committee of the 12th People's Congress of Hebei Province, 2018) and Liaoning Province (Standing Committee of the 12th People's Congress of Liaoning Province, 2018), have already borrowed and adopted this methodology in their development for setting targets for low-carbon cities, and it is envisaged that other cities and regions will adopt this method and adjust it for their own use.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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