# Sustainability Assessment of Residential Urban Areas: An Early Warning Analysis

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## Abstract

Constructing and improving residential urban areas is an eternal critical topic in the whole territorial development process. The creation of residential urban areas, which relates to human beings, social relations and activities, artificial structures, the regional environment and ancillary facilities, is connected to a series of challenges and problems, such as population pressure, environmental pollution, public safety, etc., which have to be dealt with carefully.

The concept of sustainable development has highlighted the impossibility of separating environment from development. For this reason, sustainability assessment should be based on multidisciplinary approaches that reflect the complex network of interactions between human and environmental systems.

This paper aims at integrating two different approaches in the sustainability assessment context: the environmental indicator systems and the early warning analysis. The objective is to provide a tool that is able to inform the Decision Maker on whether residential urban areas are developing sustainably and healthily or not, and on how to prevent them in advance from suffering too much or developing too quickly.

The work discusses how to establish appropriate early warning indicators and which methods and modeling can be used for the final analysis. In order to give more substance to the dissertation, the paper considers an application to a real case concerning the development of a new residential area in China.

***Keywords**: urban residential areas, real estate market, sustainable development, environmental indicators, Early Warning System.*

# 1 Introduction

It has been generally agreed that the environment is one of the main elements that causes the development of a certain territory. Natural resources are the basic elements for the ecosystem and human life and they cannot be indefinitely exploited without the risk of depletion or deterioration. Thus, it is necessary to move from an economic efficiency based approach to a more wide-ranging vision, based on the concept of sustainable development. Sustainability is a multi-dimensional concept that takes into account different elements of territorial development, such as economic growth, well-being of population, environmental quality, etc. (Bruntland, 1987). Since the early '90s many countries and international organizations have been working on sustainable development assessment by means of specific indicators (World Bank, 1987; OECD, 2003; Lisa, 2002). With specific reference to urban areas, the indicator approach is useful to give information about the sustainability condition of the system under examination and it can be used in order to make previsions about future sustainably trends (Bottero & Mondini; 2003; Brandon & Lombardi, 2005; Nessa & Montserrat, 2008). This is of particular importance in the context of emerging countries, where large urban development are going on very quickly and the necessity of tools able to predict the future sustainability levels is real.

This paper aims at integrating two different approaches in the sustainability assessment context: the environmental indicator systems and the early warning analysis. The objective is to provide a tool that is able to inform the Decision Maker on whether residential urban areas are developing sustainably and healthily or not, and on how to prevent them in advance from suffering too much or developing too quickly. After the introduction, the paper is organized as follows: section 2 illustrates the main sustainability indicator systems that are available in the context of residential urban areas, section 3 presents the Early Warning Systems (EWS) theory, section 4 focuses on the methodology for integrating the indicators approach and the EWS, section 5 shows the application of the proposed methodology to a real case, section 6 discusses the results of the application performed and section 7 contains the main conclusions that it is possible to derive from the work done.

# 2 Sustainable Development Indicators and Residential Urban Areas

An indicator is a parameter which is associated with an environmental phenomenon, which can provide information on the characteristics of the event in its global form (OECD, 2003). Many indicators are available for sustainable development assessment. Among the several indicator systems, mention can be made to the following four sets: three of them are related to international and European organizations that work in the field of sustainable development, while the last one concerns a particular indicator system which has been set up by a Chinese organization.

- The Organization for Economic Cooperation and Development (OECD) has been working on environmental indicators since 1989. The work of OECD mainly focuses on indicators that have to be used in national, international and global decision making; furthermore the approach may also be used to develop indicators at a sub-national or eco-system level (OECD, 2003);
- The United Nations Commission on Sustainable Development (UNCSD) produces some indicator sets in the field of sustainability assessment. UNCSD provides a very useful and timely forum for the discussion of national-level indicators with the involvement of governments, international organizations and various stakeholders. UNCSD indicators play an important role in "helping countries make informed decisions concerning sustainable development", and they are "applied and used in many countries as the basis for the development of national indicators of sustainable development" (United Nations, 2007);
- The European System of Social Indicators (EUSI) is part of a cross-national European project which began in the late 1990s and which aims at monitoring and assessing welfare development and social change in Europe (Berger-Schmitt & Noll, 2000). The EUSI framework links sustainability to other welfare concepts, such as social cohesion, social exclusion, social capital and quality of life;
- The Chinese Academy of Sciences, through the Chinese Urban Development Centre (CUDC), has proposed an indicator system for urban sustainability assessment (CUDC, 2002). This system concentrates on the strategic context, strategy objective, strategy mission and the strategy design of sustainable urban development in China.

As far as residential urban areas are concerned, the above mentioned sustainability indicator systems focus on different issues, such as environmental quality, well-being of the population, economic aspects, etc. Table 1 gives a representation of the indicators that are available for the assessment of the sustainable development of residential urban areas.

## 3 The Early Warning Systems (EWS)

Generally speaking, the Early Warning System (EWS) theory refers to particular models that are able to identify weaknesses and vulnerabilities of a system and to send timely and correct signals about crisis in order to react to emerging problems and to take specific measures. It is possible to find a great deal of research works on EWS devoted to macro-economy and finance (Matthieu & Marcel, 2006; Tae et al., 2004; Jie & Hui, 2009) and the real estate market (Huang & Wang, 2005). Furthermore there are many other fields related to their application: natural hazard disasters (Guido et al., 2006, UNEP, 2006), energy strategies (Jiansheng et al., 2007), project management (Nikander & Eloranta, 2001), etc. Research in different fields improves the systematic nature of the early warning theory and extends its application.

Table 1: Main indicators for sustainable development assessment of urban residential urban areas.

| | OECD | UNCSD | EUSI | CUDC |
|---|---|---|---|---|
| Housing | | | • Relative size of dwelling stock:<br>• Room and living space per person;<br>• Availability of housing services;<br>• Dwellings in deficient state of repair. | • Living space per capita. |
| Economy | • Growth and structure of GDP;<br>• Private and public consumption expenditure;<br>• Pollution abatement and control expenditure;<br>• Water treatment and noise abatement expenditure;<br>• Official Development Assistance. | • GDP per capita;<br>• Intensity of energy use, total and with reference to the different economic activities. | • Percentage of owners;<br>• Households living in one-family houses;<br>• Income related inequality;<br>• Burden of housing costs;<br>• Average rent. | • Urban economic aggregate;<br>• GDP per capita;<br>• Amount of residential investment;<br>• Exploitation of real estate; Average wages;<br>• Urban housing price. |
| Environment | • Urban air emissions;<br>• Population exposure to air pollution and noise;<br>• Ambient water conditions in urban areas;<br>• Green spaces. | • Ambient concentration of air pollution in urban areas;<br>• Share of renewable energy sources in total energy use;<br>• Generation of waste;<br>• Waste treatment and disposal. | • Noise pollution;<br>• Air pollution;<br>• Accessibility of green space;<br>• Built up land per inhabitant;<br>• Crime in residential areas;<br>• Environment-friendly energy sources for heating;<br>• Energy consumption for space heating;<br>• Energy loss per building;<br>• Insulation of housing stock. | • Urban land areas;<br>• Average water resource per capita;<br>• Water supply per capita;<br>• Water consumption per capita;<br>• Electricity consumption per capita;<br>• Public green urban areas per capita;<br>• Green coverage ratio; |
| Society | • Population growth & density;<br>• Structure of energy supply;<br>• Road traffic volumes;<br>• Stock of road vehicles | • Proportion of population living below national poverty level;<br>• Proportion of urban population living in slums;<br>• Life expectancy at birth;<br>• Population growth rate;<br>• Dependency rate | • Shortage of space;<br>• High burden of housing costs;<br>• Satisfaction with housing situation;<br>• Subjective safety in the residential area,<br>• Satisfaction with neighborhood;<br>• Overcrowded dwellings;<br>• Lack of basic amenities | • Dependency rate;<br>• Natural population growth rate;<br>• Urban infrastructures; |

The EWS procedure can be reduced to 6 aspects in generally (Figure 1): defining the objective is the foundation of the Early Warning System, the quantitative and qualitative analysis of the indicators and the system structure is the critical process, and the final results should explicitly predict the future danger. In order to achieve the predictive function, the EWS are normally developed through mathematical methods and software, such as regression analysis and MATLAB.

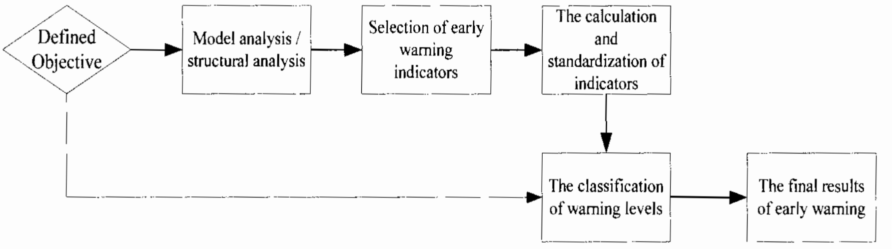


Figure 1: The Early Warning System procedure.

# 4 The Integration of Sustainable Development Indicators in Early Warning Systems

## 4.1 General overview

According to the EWS theory, the assessment model should include two basic function parts: evaluation and prediction. The two basic function parts should be related, respectively, to historical data (previous indicators) and estimate values (future indicators). With reference to the construction of an EWS model to support the sustainability assessment process, the two function parts concern different kinds of data. As far as the previous indicators are concerned, it is possible to obtain the information required by referring to historical data derived from statistical yearbooks, social-economic development reports, environmental observations, recordings, etc. As far as the future indicators are concerned, it is possible to estimate the values two ways. One of these indicators, which are called common predicted indicators, rise or descend smoothly and regularly most of the time, e.g. GDP; for these indicators it is possible to find exact estimate values from national development goals, urban and regional development planning, as well as from the observation of international economic organizations. The other kind of future indicators, which are called unstable predicted indicators, are variable and irregular with time. Example of this kind are the living space per capita yearly indicator and yearly urban air emissions indicator. In order to estimate the values of the unstable indicators it is necessary to use the regression analysis method.

In order to systematize the sustainability assessment indicators in an EWS, it is possible to refer to the Driving Forces-Pressure-State-Impact-Response (DPSIR) framework. This framework was first proposed by the Organization of Economic Co-operation and Development (OECD, 2003) and it has been widely used in the environmental management context, in order to integrate environmental and socio-economic indicators.

### 4.2 Methodology

The procedure, which aims at integrating DPSIR indicators and the EWS, can be divided into 5 steps, as follows:

***Step1. Selection of indicators***

The DPSIR framework is able to illustrate the complexities of the system interactions in sustainable development and urban residential areas. The framework can be summarized as follows:

- Driving Forces are processes and anthropogenic activities that are able to cause pressure during the development of residential urban areas; in other words, they are the reasons for the changes in the development process.
- Pressures are the direct stresses, that derive from the anthropogenic activities and which affect the environment, economy and society.
- State reflects the actual conditions of residential urban areas;
- Impact is the measure of the environmental effects due to the development of residential urban areas;
- Response refer to specific actions oriented towards reducing pressure and promoting development in terms of economic or administrative measures.

The availability and reliability of data, the usability of the available data within the DPSIR framework, and the sensitivity of indicators to reflect the underlying social and economic processes have been used as the criteria to establish the indicator system proposed in this work. The indicator system contains different kinds of indicators including social, economic, environmental and housing indicators. Among the several sustainability assessment indicators identified in Table 1, we only selected a synthetic and concise indicator system which is suitable for dealing with the Early Warning System. Table 2 represents the 23 indicators selected for the application of the EWS for the sustainability assessment of urban residential areas, according to the DPSIR framework.

In this way, the overall system is described as different layers: categories of the DPSIR framework, thematic areas and indicators. The structure here illustrated is represented in Figure 2.

Table 2: Early Warning indicators for the sustainable development of residential urban areas.

| Thematic Area | Indicator | DPSIR Category |
|---|---|---|
| Housing | • Relative size of dwelling stock; | S |
| | • Living space per capita; | S |
| | • Availability of flushing toilet, bath/shower and central heating; | S |
| | • Dwellings in deficient state of repair | S |
| Economy | • GDP; | D<br>P |

| | | |
|---|---|---|
| | • Average urban housing price; | P |
| | • Average rent price. | R |
| | • Exploitation and investment of real estate; | R |
| | • Environmental pollution abatement and control expenditure; | R |
| | • Official Development Assistance. | |
| Environment | • Crime in residential area; | P |
| | • Built up land per inhabitant; | P |
| | • Urban air emissions (SOx,NOx,VOC); | I |
| | • Ambient water conditions in urban areas; | I |
| | • Generation of waste; | I |
| | • Green coverage ratio; | I |
| | • Share of renewable energy sources in total energy use. | R |
| Society | • Natural population growth rate; | D |
| | • Urban infrastructure; | D |
| | • Dependency rate; | P |
| | • Road traffic volumes. | P |
| | • Proportion of population living below national poverty level; | S |
| | • Stock of road vehicles. | S |

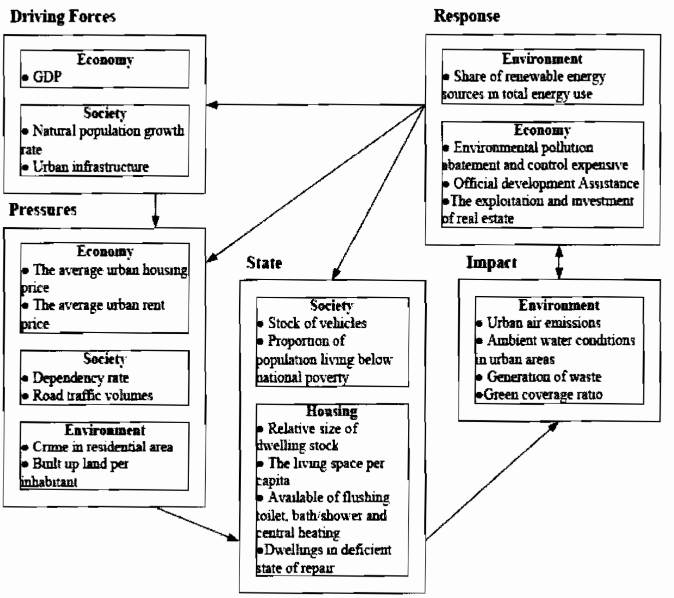


Figure 2: The structure of DPSIR framework for early warning indicators.

### *Step2. Determination weight of indicators*

The weight of each indicator was determined using Multicriteria Analysis (MCA). The Analytic Hierarchy Process (AHP) method (Saaty, 1980) has been developed. On the basis of the knowledge about sustainability assessment of urban residential areas, it is possible, using the AHP, to discuss the weight of each indicator by consulting the opinions from experts. Judgment matrixes have been established. For example, Table 3, represents the judgment matrix for the comparison of the importance of the different DPSIR categories for the assessment of the sustainability of urban areas. The process has been repeated for the whole assessment system and a relative stable weight result has been reached. Table 4 represents the indicator system structure; the values in the square brackets reflect the weight of the element with reference to the overall system.

Table 3: Pairwise comparison matrix for DPSIR category assessment.

| | D | P | S | I | R | Weight |
|---|---|---|---|---|---|---|
| D | 1 | 2 | 3 | 3 | 1/2 | 0.25 |
| P | 1/2 | 1 | 2 | 2 | 1/3 | 0.15 |
| S | 1/3 | 1/2 | 1 | 1 | 1/5 | 0.08 |
| I | 1/3 | 1/2 | 1 | 1 | 1/5 | 0.08 |
| R | 2 | 3 | 5 | 5 | 1 | 0.44 |

Table 4: the early warning indicator system in the DPSIR framework.

| System | DPSIR categories | Thematic areas | Indicators |
|---|---|---|---|
| Sustainable development of urban residential areas[1] | Driving forces [0.25] | Economy [0.66] | 1: GDP [1] |
| | | Society [0.34] | 2: Natural population growth rate [0.5]<br>3: Urban infrastructures [0.5] |
| | Pressure [0.15] | Environment [0.33] | 4: Crime in residential areas [0.34]<br>5: Built up land per inhabitant [0.66] |
| | | Society [0.33] | 6: Dependency ratio [0.5]<br>7: Road traffic volumes [0.5] |
| | | Economy [0.34] | 8: Average urban housing price [0.75]<br>9: Average rent price [0.25] |
| | State [0.08] | Housing [0.75] | 10: Relative size of dwelling stock [0.24]<br>11: Availability of flushing toilet, bath/shower and central heating [0.13]<br>12: Living space per capita [0.53]<br>13: Dwellings in deficient state of repair [0.1] |
| | | Society [0.25] | 14: Stock of road vehicles [0.25]<br>15: Proportion of population living below national poverty [0.75] |
| | Impact [0.08] | Environment [1] | 16: Urban air emissions [0.28]<br>17: Generation of waste [0.28]<br>18: Ambient water conditions in urban areas [0.28]<br>19: Green coverage ratio [0.16] |
| | Responses [0.44] | Environment [0.34] | 20: Share of renewable energy sources in total energy use [1] |
| | | Economy [0.66] | 21: Environmental pollution abatement and control expenditure [0.4]<br>22: Official Development Assistance [0.2]<br>23: Exploitation and investment of real estate [0.4] |

***Step3. Standardization of the indicator value***

The selected indicators influence the sustainability level of residential urban areas according to two different directions: for some indicators (for example, “green coverage ratio” or “availability of toilet, bath, shower and central heating”), the higher the value, the higher the sustainability level, while for other indicators (fro example, “urban air emissions” or “crime in residential areas”), the lower the value, the higher the sustainability level. In order to take into consideration the positive and negative directions of the indicators, it is necessary to calculate the standard value of each indicator as in equation (1), where $x_i$ is the standard value of indicator $i$ in the temporal period considered for the analysis, $x$ is the actual value of indicator $i$ in each part of the considered period, $\overline{x}$ is the average value of indicator $i$ in the period and $s$ is the standard deviation of the indicator $i$ in the period.

$$x_i = \begin{cases} 0.5 + \dfrac{x - \overline{x}}{s^2} & \text{(Positive direction)} \\ \\ 0.5 - \dfrac{x - \overline{x}}{s^2} & \text{(Negative direction)} \end{cases} \tag{1}$$

Step4. Calculation results

On the basis of steps 2 and 3, it is possible to obtain the value of the subsystems layer related to the DPSIR categories, as in equation (2), where $Y_k$ is the value of the subsystem layer related to category $k$ of the DPISR framework, $\sigma_j$ is the weight of thematic area $j$ corresponding to $Y_k$, $n$ is the number of the thematic areas under $Y_k$, $w_i$ is the weight of indicator $i$, $m$ is the number of indicators under thematic area $j$ and $x_i$ is the standard value of indicator $i$.

$$Y_k = \sum_{j=1}^{n} \sigma_j \left( \sum_{i=1}^{m} w_i x_i \right) \tag{2}$$

The final value of the sustainability level of the system is derived from the weighted sum of the five subsystems $k$, as in equation (3), where $Z$ is the final value of sustainability of the system, $\mu_k$ is the weight of category $k$ of the DPSIR framework and $Y_k$ is the value of category $k$.

$$Z = \sum_{k=1}^{5} \mu_k Y_k \tag{3}$$

It is possible to observe that $Z$ is a composite index that results from the value of the Driving Forces, Pressure, State, Impact and Response categories; furthermore, the value of $Z$ is included in the (0, 1) domain.

*Step5. Early warning results*

After the calculations made in step 4, it is possible to obtain a set of values of the composite index Z and of the Driving forces, Pressures, State, Impact or Response subsystems for the different years of the period considered in the analysis, as illustrated in Table 5 where $n$ represents the single year in the considered period.

Table 5: Early Warning results for the assessment of the sustainability level in the considered period (year 1 – year n+2).

| | Historical data | | | | Estimate value | |
|---|---|---|---|---|---|---|
| | 1 | 2 | ... | n | n+1 | n+2 |
| Driving forces | $Y_{D1}$ | $Y_{D2}$ | ... | $Y_{Dn}$ | $Y_{Dn+1}$ | $Y_{Dn+2}$ |
| Pressure | $Y_{P1}$ | $Y_{P2}$ | ... | $Y_{Pn}$ | $Y_{Pn+1}$ | $Y_{Pn+2}$ |
| State | $Y_{S1}$ | $Y_{S2}$ | ... | $Y_{Sn}$ | $Y_{Sn+1}$ | $Y_{Sn+2}$ |
| Impact | $Y_{I1}$ | $Y_{I2}$ | ... | $Y_{In}$ | $Y_{In+1}$ | $Y_{In+2}$ |
| Response | $Y_{R1}$ | $Y_{R2}$ | ... | $Y_{Rn}$ | $Y_{Rn+1}$ | $Y_{Rn+2}$ |
| Z | $Z_1$ | $Z_2$ | ... | $Z_n$ | $Z_{n+1}$ | $Z_{n+2}$ |

It is possible to observe that when *Z* is very low, it will be difficult to continue a sustainable urban development, because some indicators indicate a bad performance (for example, "GDP" or "urban infrastructures"). However, the previous consideration does not mean that the higher the value of *Z*, the higher the sustainability level of the system. This leads to recognize a five-grade scale for the classification of the warning levels (Table 6) (Chen & Chen, 1992). Mentions should be made to the fact that the choice of the threshold values which determine the warning signals strictly depends on the structure of the model being developed and on the characteristics of the system under examination. In the present application, the threshold values have been derived from previous works considering the application of the EWS theory for assessing housing development in NanJing (Qiu et al., 2006).

Table 6: The five-grade classification of the warning level.

| Grade | Value | Qualitative evaluation | Warning district | |
|---|---|---|---|---|
| I | $Z>0.86$ | Develop excessively | Yellow light | Warning |
| II | $0.72<Z\leq 0.86$ | Develop quickly | Green light | No warning |
| III | $0.48<Z\leq 0.72$ | Develop steadily | | |
| IV | $0.34<Z\leq 0.48$ | Bear pressure | Yellow light | Warning |
| V | $Z\leq 0.34$ | Bear great pressure | Red light | |

The warning levels that have been identified in Table 6 can be explained as follows: *i)* Z is very large in grade I. This shows that in the social, economic and environmental aspects the residential urban areas are developing excessively. For example, the excessive emphasis on the environmental quality of residential areas can lead the actual demands of the inhabitants being ignored; this is particularly true in emerging countries, where the need to raise income and welfare is higher that the need to have green spaces. This grade will be warning with a yellow light. *ii)* Z has a reasonable value in grade II and III. This means that the residential urban areas are developing at a steady rate (grade III) or quickly (grade II). This is the optimum condition for sustainable development. These two grades will not be warning with a green light. *iii)* Z has a smaller value in grade IV than in grades II and III. In this case, the sustainable development of residential urban areas is able to bear the pressure. The situation can be ameliorated by a sequence of special measures adopted to strengthen environmental, social and economic development. This grade will be warning with a yellow light. *iv*) Z has the smallest value in grade V. At this point, the sustainable development of residential urban areas is bearing great pressure. It can be observed that the social-economic sustainability and environmental sustainability confront a major obstacle. This grade will be warning with a red light.

## 5 Application to a Chinese Case Study

The considered study case refers to the city of Nanjing which is the provincial capital of JiangSu in China. The urban area of the Nanjing megalopolis has been growing rapidly, from 2599 km$^2$ in 2001 to 4723 km$^2$ in 2008. The population has registered a great variation over the years, from 3,71 million inhabitants in 2001 to 5,41 million inhabitants in 2008. The application of the EWS model for the sustainability assessment of the Nanjing urban areas has been performed using the 23 indicators which have been observed through a period of 10 years (2001-2010). Table 7 gives a short description of the 23 indicators used in the application.

Table 7: Description of the quantitative indicators used in the application (elaboration from different sources).

| | Indicators | Description | Unit of measure |
|---|---|---|---|
| 1 | GDP | GDP stands for Gross domestic product and it reflects the sum of private consumptions, gross investments, government spending and exports, while the imports are subtracted. | Billion |
| 2 | Natural population growth rate | This represents the births and deaths in the population of a country or city. It does not take into account migration. | ‰ |
| 3 | Urban infrastructures | This represents the investments in urban infrastructures in a year. | Billion |
| 4 | Crime in residential area | This is indicated by the number of criminal registered cases per unit of 10000 people per year. | n/y |
| 5 | Built up land per inhabitant | This is indicated by the business-land area issued to the public by the municipal government. | million/m$^2$ |
| 6 | Dependency ratio | This represents an age-population ratio who are usually not in the labor force who registered at an employment agency and those who are usually in the labor force. | % |
| 7 | Road traffic volumes | This aims at measuring the urban traffic condition and it is represented by the number of public transportation vehicles per unit of 10000 people. | n/10000 p |
| 8 | Average urban housing price | This is the ratio of housing prices and the basic price in 2001. | % |
| 9 | Average rent price | This is indicated by the price index of housing rent. It considers the rent in 2001 as a basic price. | % |
| 10 | Relative size of dwelling stock | This is indicated by the floor area completed in one year. | million/m$^2$ |
| 11 | Availability of flushing toilet, bath/shower and central heating | This varies from a 0-1 point scale where the value 0 stands for unavailability and the value 1 stands for total availability. | n. |
| 12 | Living space per capita | This reflects the average level of housing per capita. | m$^2$ |
| 13 | Dwellings in deficient state of repair | This indicates the households or units relocated due to building demolition. | n. |
| 14 | Stock of road | This is represented by the quantity of possessed family cars per | n. /100 p |

| | | | |
|---|---|---|---|
| | vehicles | 100 urban households. | |
| 15 | Proportion of population living below national poverty level | This represents the ratio of the population living below the national poverty and the full city town population. Low-income families are urban residents whose average family income is lower than the minimum living standard of NanJing city. | % |
| 16 | Urban air emissions | This considers the Air Pollution Index (API). The index has 5 grades, where: grade I (API< 50): the air quality is excellent; Grade II (50<API<100): the air quality is good; Grade III (100<API<200): light air pollution exists; Grade IV (200<API<300): medium air pollution exists; Grade V (API> 300): heavy air pollution exists. Here the indicator is obtained from the number of days in which the pollution index attains Grade I and Grade II in a year. | d/y |
| 17 | Generation of waste | This reflects the domestic waste in a whole year. | million ton |
| 18 | Ambient water eonditions in urban areas | This indicates the total urban domestic water consumption volume. | million $m^3$ |
| 19 | Green coverage ratio | This represents the ratio between the green areas in the city and the overall urban area. | % |
| 20 | Share of renewable energy sources in the total energy use | This indicates the energy consumption (standard coal) for every ten thousand Chinese yuan (CNY) worth of the gross domestic product (GDP). This is an index on the energy utilization efficiency to reflect the consumption level and the saving energy and reducing consumption conditions. | million $m^2$ |
| 21 | Environmental pollution abatement and control expenditure | This indicates the complete investment concerning pollution-control projects. | million |
| 22 | Official Development Assistance | This represents the budgetary outlays from local finance for environment protection. | million |
| 23 | Exploitation and investment of real estate | This indicates the amount of investment in real estate development. | billion |

The historical values of the indicators (years 2001-2008) have been derived from specific reports of the city of Nanjing. With reference to the future values of the indicators (2009-2010), these have been estimated using regression analysis (the values for the years 2009 and 2010 for the indicators 1, 5, 14, 16 and 20 are given in the city development plan). Table 8 represents the values for the 23 indicators considered in the analysis over the years 2001-2010. The values derived from the regression analysis are shown with a border.

On the basis of the methodology described in section 4, it is possible to calculate the sustainability level of the subsystems and of the overall system from the values of the indicators of Table 8, for each year of the considered period (Table 9).

Figure 3 shows the line chart of five subsystems while Figure 4 shows the line chart of the sustainable development situation of residential urban areas in the city of Nanjing for the period 2001-2010.

Table 8: Indicator values of the Early Warning System.

| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| I1 | 121.85 | 138.51 | 169.08 | 206.72 | 224.11 | 277.38 | 328.37 | 377.5 | 416.59 | 480 |
| I2 | 1.6 | 0.7 | 0.08 | 2.29 | 2.34 | 2.18 | 2.84 | 2.51 | 3.29 | 3.71 |
| I3 | 2.98 | 3.14 | 4.3 | 5.13 | 6.33 | 7.66 | 7.32 | 10.63 | 11.65 | 13.42 |
| I4 | 70 | 77 | 71 | 68 | 95 | 90 | 70 | 74 | 69 | 61 |
| I5 | 0.27 | 1.65 | 5.7 | 2.27 | 4.69 | 5.5 | 6.85 | 3.7 | 4 | 2.7 |
| I6 | 3.59 | 4.13 | 4.18 | 4.03 | 3.35 | 3.33 | 3.3 | 3.16 | 2.65 | 2.25 |
| I7 | 10.85 | 9.84 | 10 | 9.63 | 11.4 | 13.8 | 14.2 | 15 | 17 | 20 |
| I8 | 100 | 114.6 | 125.8 | 145.1 | 156.4 | 163.1 | 173.9 | 194.1 | 202 | 213.2 |
| I9 | 100 | 99.4 | 103.8 | 109 | 109 | 109.4 | 111.4 | 125.3 | 127.2 | 133.7 |
| I10 | 3.09 | 3.75 | 3.36 | 5.6 | 5.65 | 6.71 | 5.79 | 8.91 | 9.26 | 10.41 |
| I11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| I12 | 19 | 20.1 | 21.11 | 21.61 | 24.3 | 25.21 | 26.08 | 32.21 | 34.29 | 38.07 |
| I13 | 13057 | 20032 | 21308 | 13500 | 15000 | 15000 | 16000 | 25000 | 24381 | 27965 |
| I14 | 0.09 | 0.3 | 1.6 | 2 | 4.88 | 6.38 | 6.63 | 13 | 13.3 | 17.3 |
| I15 | 0.95 | 1.6 | 1.99 | 2.12 | 2.4 | 2 | 2 | 2 | 1.48 | 0.98 |
| I16 | 247 | 215 | 297 | 295 | 304 | 305 | 312 | 322 | 320 | 330 |
| I17 | 1.33 | 1.00 | 1.52 | 1.66 | 1.69 | 1.62 | 1.62 | 1.66 | 1.59 | 1.5 |
| I18 | 149.42 | 242.77 | 138.62 | 144.17 | 154.09 | 415.29 | 398.14 | 409.17 | 565.3 | 689.41 |
| I19 | 40 | 42.9 | 43.51 | 44.46 | 44.94 | 45.49 | 45.92 | 46.5 | 46.05 | 45.67 |
| I20 | 1.8 | 1.5 | 1.43 | 1.37 | 1.36 | 1.31 | 1.25 | 1.18 | 1.15 | 1.09 |
| I21 | 176.39 | 133.12 | 162.6 | 233.03 | 205.93 | 527.12 | 585.91 | 836.8 | 1100.4 | 1406.3 |
| I22 | 73 | 129 | 114 | 200 | 200 | 216 | 527 | 385 | 548 | 653 |
| I23 | 11.1 | 13.76 | 18.38 | 29.29 | 29.61 | 35.12 | 44.6 | 50.82 | 58.23 | 66.17 |

Table 9: Sustainability level of the subsystems and of the overall system.

| Year | Subsystem (B) | | | | | Subsystem (A) | |
|---|---|---|---|---|---|---|---|
| | Driving forces | Pressures | State | Impact | Response | Sustainable development of urban residential asreas | |
| 2001 | 0.09 | 0.05 | 0.05 | 0.05 | 0.14 | 0.38 | Yellow |
| 2002 | 0.09 | 0.04 | 0.03 | 0.1 | 0.14 | 0.4 | Yellow |
| 2003 | 0.09 | 0.08 | 0.02 | 0.03 | 0.14 | 0.36 | Yellow |
| 2004 | 0.12 | 0.05 | 0.03 | 0.03 | 0.15 | 0.38 | Yellow |
| 2005 | 0.13 | 0.06 | 0.03 | 0.03 | 0.16 | 0.41 | Yellow |
| 2006 | 0.12 | 0.09 | 0.04 | 0.03 | 0.2 | 0.48 | Yellow |
| 2007 | 0.14 | 0.1 | 0.03 | 0.03 | 0.25 | 0.55 | Green |
| 2008 | 0.15 | 0.08 | 0.04 | 0.04 | 0.32 | 0.63 | Green |
| 2009 | 0.16 | 0.11 | 0.06 | 0.04 | 0.35 | 0.72 | Green |
| 2010 | 0.16 | 0.12 | 0.08 | 0.04 | 0.4 | 0.76 | Green |

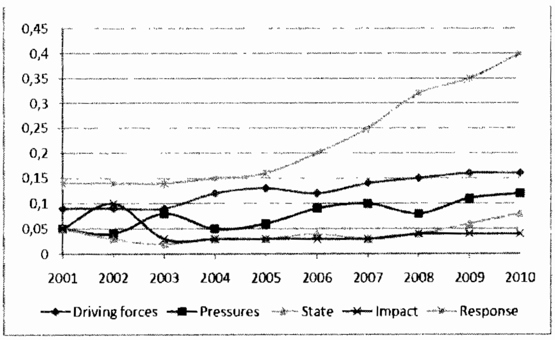


Figure 3: Line chart of the five subsystems.

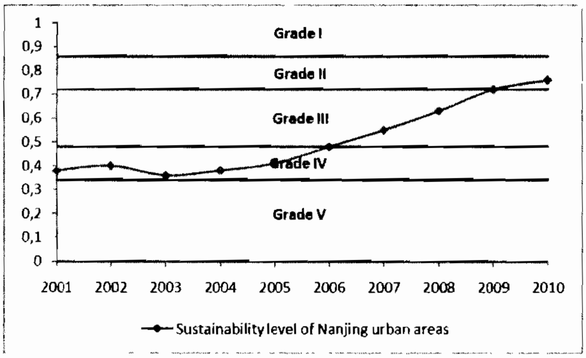


Figure 4: Line chart of the overall system.

## 6 Discussion

The application of the DPSIR/EWS model to the Nanjing urban area has led to the identification of the sustainability trend of the city for the period 2001-2010. Taking into consideration the five subsystems (Figure 3), it is possible to observe generally that the State and Impact categories develop smoothly in the considered period, even if some alterations emerge. If we consider, for example, the Impact category, it is possible to note that a discontinuity occurs in the year 2002; this is due to the high value of the indicator "water conditions in urban areas" in this year. Notable variations appear in the line chart of the Driving Forces, Pressure and Response categories. The Driving Forces and Response in particular rise steadily over the years; this is due to the increase in the values of specific indicators, such as "GDP" (Driving Forces category), "Environmental pollution abatement and control expenditure", "Official Development Assistance" and "Exploitation and investment of real estate" (Response category). The Pressures category generally increase with a fluctuant state in the considered period. With reference to the overall system under examination (Figure 4), the model shows that the sustainability level of the Nanjing urban area has an ascending trend, with a good performance (green light) for the latter part of the considered period (from 2007 to 2010). It is possible to notice that the bad performance of the system in the first part of the period is pushed up towards more sustainable levels by the ascending trend of the Driving Forces and Response categories.

The results of the analysis show that the DPSIR/EWS integrated model is able to reflect the reality under examination and it offers a useful tool that can be used to represent the several dimensions of the problem.

## 7 Conclusions

The paper has shown an evaluation model based on the combined use of the DPSIR indicators framework and the Early Warning Systems (EWS) for the sustainability assessment of urban areas. The application of the model has been performed on a real case concerning the city of Nanjing in China. The simulation indicates that the sustainability of urban residential areas in Nanjing City is good at the moment and new positive performance will be scored in 2011. The work shows that the combined model is efficient in representing the sustainability trend of urban residential areas and it is a useful tool to support the decision process. The model allows the sustainability level of an urban area to be understood through a monitoring and measuring of the different elements of the environmental system. Furthermore, the model has the characteristic of flexibility and can easily be adapted to different contexts. The model described herein could offer a useful support in the context of the emerging countries, where urban areas are increasing and proper monitoring are missing. This model allows managers and DMs to observe the signals provided by the analysis and to interpret them according to their experience. In this sense, they will be able to gain information on emerging problems or opportunities and to take appropriate actions or countermeasures.

However, there are still a number of opportunities for expanding the study and for validating the results obtained herein. Firstly, only core-indicators were considered in this work. It would be of scientific interest to add other indicators resulting from policies and strategies. Secondly, further research would be required considering the data collection and optimization of the early warning model. Finally, mention can be made of the determination of the weights of the different elements of the model, which could be improved taking into consideration non only the judgments of experts but also the opinion of the population involved by means of specific focus groups and questionnaires.

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