INVOKING HOUSEHOLD COOPERATION OF CO2 EMISSION REDUCTION

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1 Introduction

- **"The tragedy of commons"**

Hardin (1968) published an article on the dilemma of the commons. Commons refers to any resource (e.g. fish, water, forest, or clean air) shared by a group of people. Every member society has the right to take from and add to the commons pool for resources. To accumulate wealth, each member believes that he/she has to acquire one unit of resource or dump one unit of waste while distributing one unit of cost across all the members with whom the resources is shared. Thereby, the individual gain appears large and the cost very small. Ultimately, as population grows and greed runs rampant, the system collapses and ends in "the tragedy of the commons".

Human activities have changed the composition of the atmosphere, and are responsible for the excessive increase of CO2 in the air (Karl and Trenberth, 2003). Reduction of the CO2 emitted through human actions to an acceptable level is must be a global objective of the modern community (Kyoto Protocol, 1992). However, global objective and individual benefits may be contradictory. Reducing CO2 emission is then a type of the commons dilemma. Society shares the atmosphere, in which they freely emit CO2. In terms of households, the environmental load from one household is then multiplied by all the households in its area. Reduction of CO2 emissions would limit the household's activity and could add additional cost to the family's budget; those that do nothing for reducing CO2 emission pay nothing. Obviously, there is payoff from cooperative activity. According to game theory, the defector seems always to win in the game of commons dilemma (Yamamoto S, 2003). As a result of these circumstances, global warming is likely to reach damaging levels. The cost of controlling carbon emissions is high and there is always the mirage of a hydrogen dependent economy (Kennedy, 2003). According to Hardin (1968), there is no technical solution to the problem. Can the catastrophe not be redressed?

The payoff can be directly influenced through the cost/benefit relation of behaviors, for example via taxes and financial incentives. It must pay to behave in an environmentally-responsible way (Mosler, H.-J. 2001). This study considers introducing strategies which cause changes in payoff and support the cooperative activities.

To prohibit the defection behaviors, the strategy of levying maintenance charge for environment recovering is usually considered a legal solution. While in micro-economic, one of the most remarkable efforts is the creation of CO2 Emission Trading Scheme (CETS)

- **Purpose**

1) How the CETS for households be designed?
2) How do the strategies influence the payoff function and the household cooperation in reducing CO2 emission?
3) Is it possible to increase social cooperation by applying the strategies?

2 CETS for households

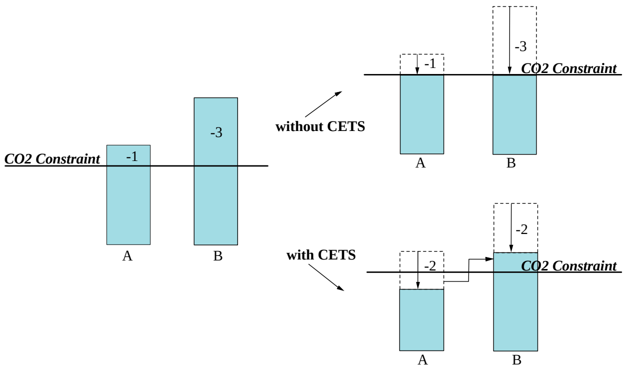


Fig. 1 CETS for Companies

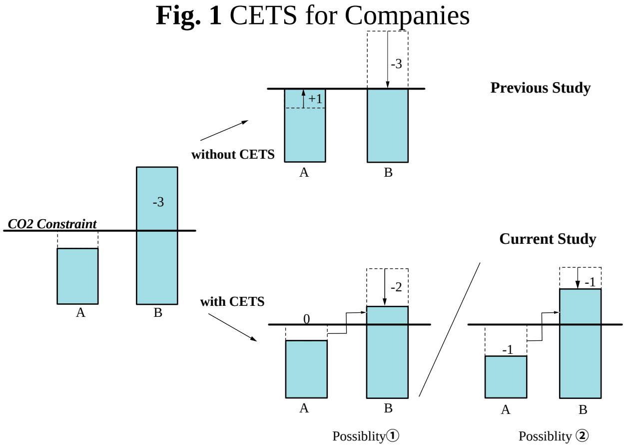


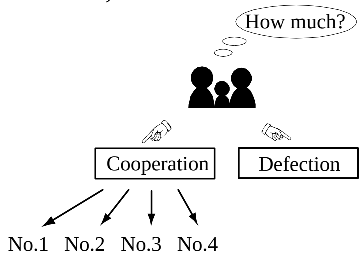
Fig.2 CETS for Households

3 Method and Materials

- **MAS based model**

Multi-Agent Simulator is adopted to construct a model, in which a household acts as an agent. The agent does not affect each other directly. However, as a part of the environment the behaviors of an agent will change the sensory inputs of the others, and then influence their own behaviors. The number of households in the city is assumed constant. The management for controlling HACO2 gives a limit of CO2 emission acceptability in the city.

Agent→ household;



Environment→ urban space

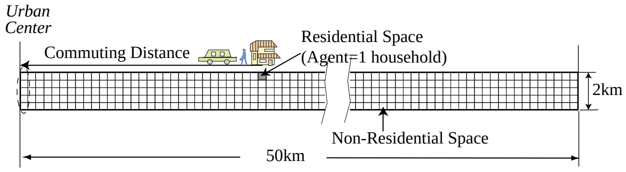


Fig.3 MAS-based model

- **Payoff function**

if *HACO2> CO2 constraint* then

$$f(b,nC)=\begin{cases}-RC-(N-nC-1)\times L & if \quad b=C\\ -(N-nC)\times L & if \quad b=D\end{cases}$$

if *HACO2< CO2 constraint* then

$$f(b,nC)=\begin{cases}-RC-(N-nC-1)\times L+PS & if \quad b=C\\ -(N-nC)\times L & if \quad b=D\end{cases}$$

where *f* represents the expense to an agent (the payoff value), *b* represents either C or D behavior, *RC* represents the cost of reduction, *N* represents the number of households in the city (N = {1, 2, …, n}), *nC* represents the number of cooperators (*nC* = 0, 1, …, n – 1), *L* represents the unit maintenance charge (monetary unit) (L >= 0), and *PS* represents the profit from CEA selling (monetary unit).

If *PS* is greater than *RC*, Agent-C could receive a greater payoff than Agent-D. The greater the reduction in CO_2 emissions, the more profit Agent-C could earn. It is likely that this mechanism will invoke greater social cooperation toward reducing CO_2 emissions.

- **HACO2 reduction process**.

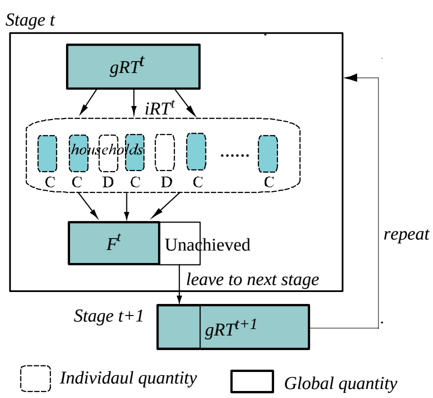


Fig. 4 Reduction Process

The reduction process of $HACO_2$ can be divided into several stages. The global reduction target is to cut m% of total $HACO_2$ emitted from all households within a designed period. Figure 4 illustrates the flow of the reduction process.

- **Simulation**

Environmental initial condition**:** R^0 =0.5.

Global reduction target: *m =10%, T=100*

Terminate condition: stops when the period is over or when the global reduction target is achieved.

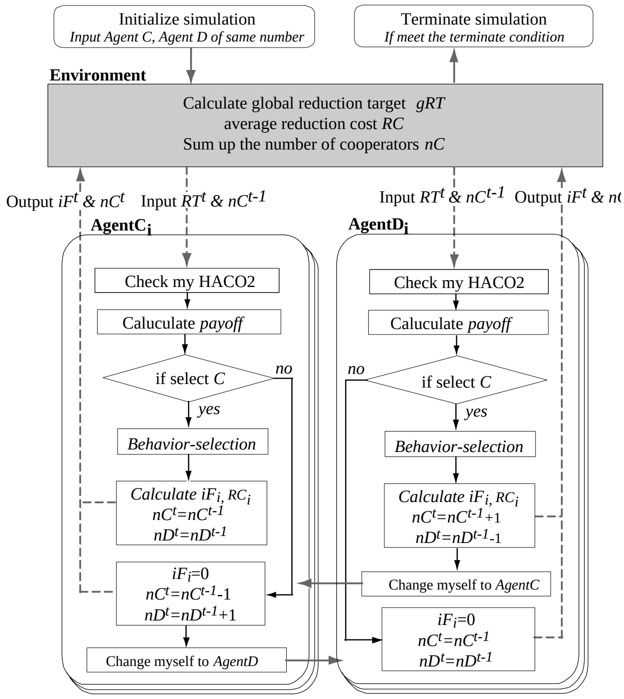


Fig. 5 Simulation Flow

4 Results and Discussion

- **Results of Introducing Maintenance Charge**

When *p=0*, *R* is always 0. The result indicates that, almost no household cooperates in CO2 emission reduction if there is no legal prohibition on defection or inducing household's behaviors. When *p* is a little bit larger than 0 (such as *p=0.1*), *R* is relative stable at around 0.3. However, there is no obvious change in *R*, even if *p* continuously increases. This is because the difference between payoff of Agent-C and Agent-D is too small to encourage the cooperative behaviors. Extremely large maintenance charge may result in discouragement to both defector and cooperator.

- **Results of Introducing CETS**

Fig.6 illustrates social cooperation (*R*) varying with *a* and *p*. One dot denotes a combination of *a, p,* and *R*. The dots with a low *R* gather at the locations at which *a=0*. Only introducing maintenance charge, is difficult to obtain the cooperation from more than 30% of households in the city. When *a>0*, which means introducing CETS to CO2 emission reduction, *R* values are relative stable at around 0.5. CETS is efficient on invoking the cooperation. The high social cooperation appears (*R*>0.6) appears and the highest *R (R=0.62)* is located where *a=2* and *p=1*. However, thousands of the simulations show it is impossible to obtain *R>0.65*.

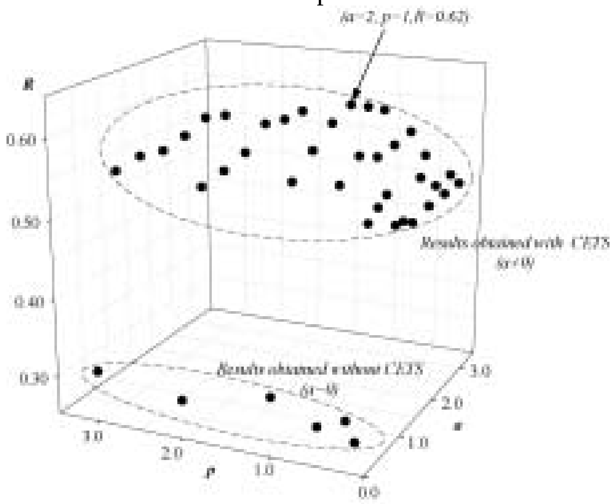


Fig.6 Change in Social Cooperation (*R*) with *a* and *p*

- **Housing arrangement and Household's Behavior-selections**

The following results are from the situations performed by setting *a=2, p=1*, which is proved leading to the highest *R*.

Housing arrangement turns compact caused by the strategies (Fig.8). However, it is obviously less compact than the result in previous study (Fig. 9). The reason can be explained by the changes in household's behavior-selections. Fig.8 also illustrates the household's behavior-selections during the reduction process. It shows extremely difference to the previous study. In order to clarify the difference, each behavior-selection is picked up from the results of previous and current study.

Fig.10 illustrates where the defective behavior happen. By introducing the strategies, all the agents, even those locate closely to urban center are encouraged taking part in emission reduction. The cooperation of CO2 emission reduction is then increased.

Fig.11 shows where the energy-saving behaviors happen. By applying the strategies, all of the agents take part in energy-saving. The greater the reduction in CO2 emissions, the more profit cooperator could earn. This mechanism invokes greater social cooperation toward reducing CO2 emissions.

- **Completion of Reduction Target**

The reduction target is not achieved in the previous study. But in this study, it is always achieved before reaching the reduction period. It is because that the completion of the global target is connecting with the household individual target (Fig 12).

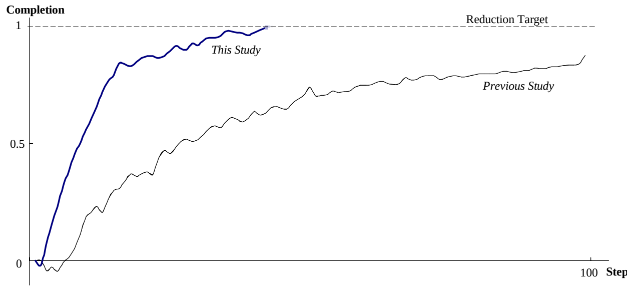


Fig 12 Completion of this study and previous study

5 Conclusions and perspectives

1) CETS is proved not only with cost-efficiency, but also promoting the process of CO2 emission reduction. If CEA is regard as a kind of resource, introducing CETS to households assures the optimal usage of the resources.

2) Levying only maintenance charges for households is ineffective to gaining the cooperation of more than 30% of the households in the city, and extremely high maintenance also discouraged cooperative behavior.

3) Higher cooperation can be obtained with the use of CETS than without CETS. While CETS is an efficient strategy to invoke cooperation, it is impossible to obtain cooperation from all households.

4) The strategies connect the global reduction target and the individual behavior-selection. The target is then achieved before the end of the period.

Payoff value can be influenced via financial incentives, such as a household CETS. This can help to reduce the total $HACO_2$ emissions in a city. Some parameters, such as the price of emission trading, are difficult to determine, but development of environmental policies could be aided by examining the combinations of parameters that this study found to be relevant to social cooperation.

This study illustrates the fact that it is impossible to obtain cooperation from all members of a community. Hardin's claim that "there is no technical solution for this problem" (1968) indicates that the problem of cooperation within the commons dilemma can only be ameliorated if opinions are changed; ideal solutions would include both structural and psychological strategies.

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【日本語要約】

環境は、多く場合共有資源である。社会構造の中には、最小ユニットとしての世帯が費用を負担せずに環境資源を使用して収益だけを受け取ろうとするインセンティブが存在するため、世帯は環境負荷低減行動を採りにくかった。都市全体で環境負荷を下げるためには、個々の世帯が都市の環境負荷を与える加害者であることに目覚める必要がある。世帯の住宅、通勤、生活などによる環境負荷を「CO2 排出量」として計算し、世帯の社会階層に関わらず、均等に年間 CO2 排出量の制約を分担することは、都市環境問題の有効な解決策であることと考え、一連の研究を展開した。これらの既往研究を基づいて、世帯の都市移住や省エネルギー行動によって、都市の世帯から排出する CO2 の量を一定の水準まで削減、維持し、環境負荷が低くかつ生活の質が高くなれる住環境を求める研究の構想がある

本研究は,都市住宅配置の視点から、世帯の年間 CO2 排出量を住宅の規模、立地、生活エネルギー消費の合計として定義し、計算した。「The Tragedy of the Commons」のジレーマ構造を分析し、都市中の世帯から排出する CO2 量の削減目標を達成するために、世帯を対象とする環境公益費（Maintenance Charge for environmental recovery）、「CO2 排出量取引（CO2 Emission Trading Scheme(CETS)）」を含めて一連の誘導施策を提案した。この仕組みは、世帯の CO2 削減協力から収益を得ることによって CO2 削減行動をさらに促進する誘導施策であると考える。Multi-Agent Simulator (MAS)を用いて、誘導施策の導入前後における世帯の都心移住や省エネルギー行動の変化を注視し、それよって都市住宅配置への影響、都市 CO2 排出量の削減効果、平均削減費用の変化などを考察した。

結論として、提案した誘導施策の導入によって、協力世帯の利得を上昇させ、社会的 CO2 削減の協力率を高水準に保つことによって、CO2 排出量削減目標の達成を確保したことが分かった。

しかしながら、協力率は 65%以上得ることができないため、構造的な施策（Structural strategy）のみで Commons の問題を解決することが難しい。心理的方策（Psychological strategy）と構造的な施策を融合させる方策が有効であると考え、課題として残した。

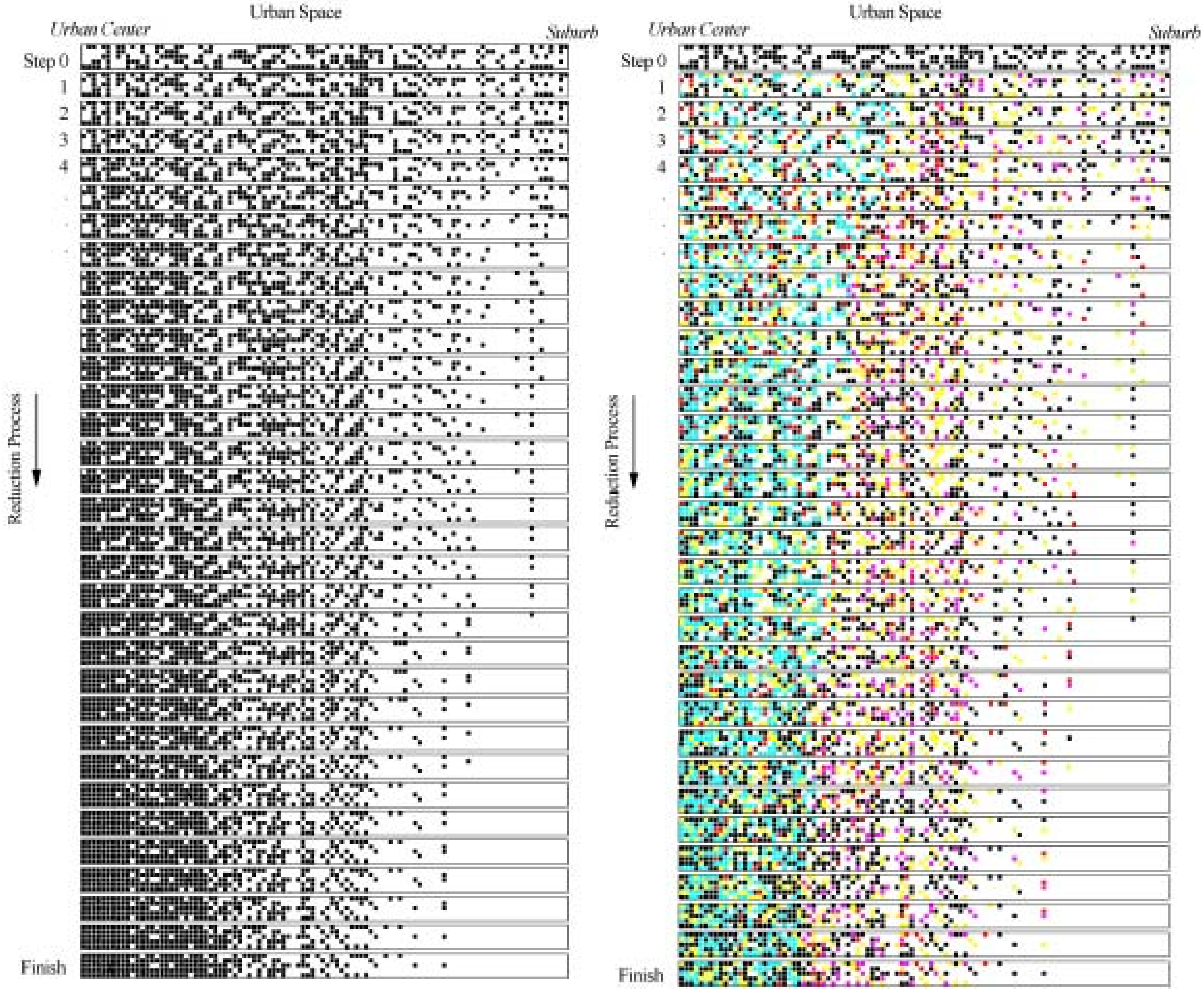

Fig 7 Housing Arrangement and Behavior-Selection Resulted in this Study

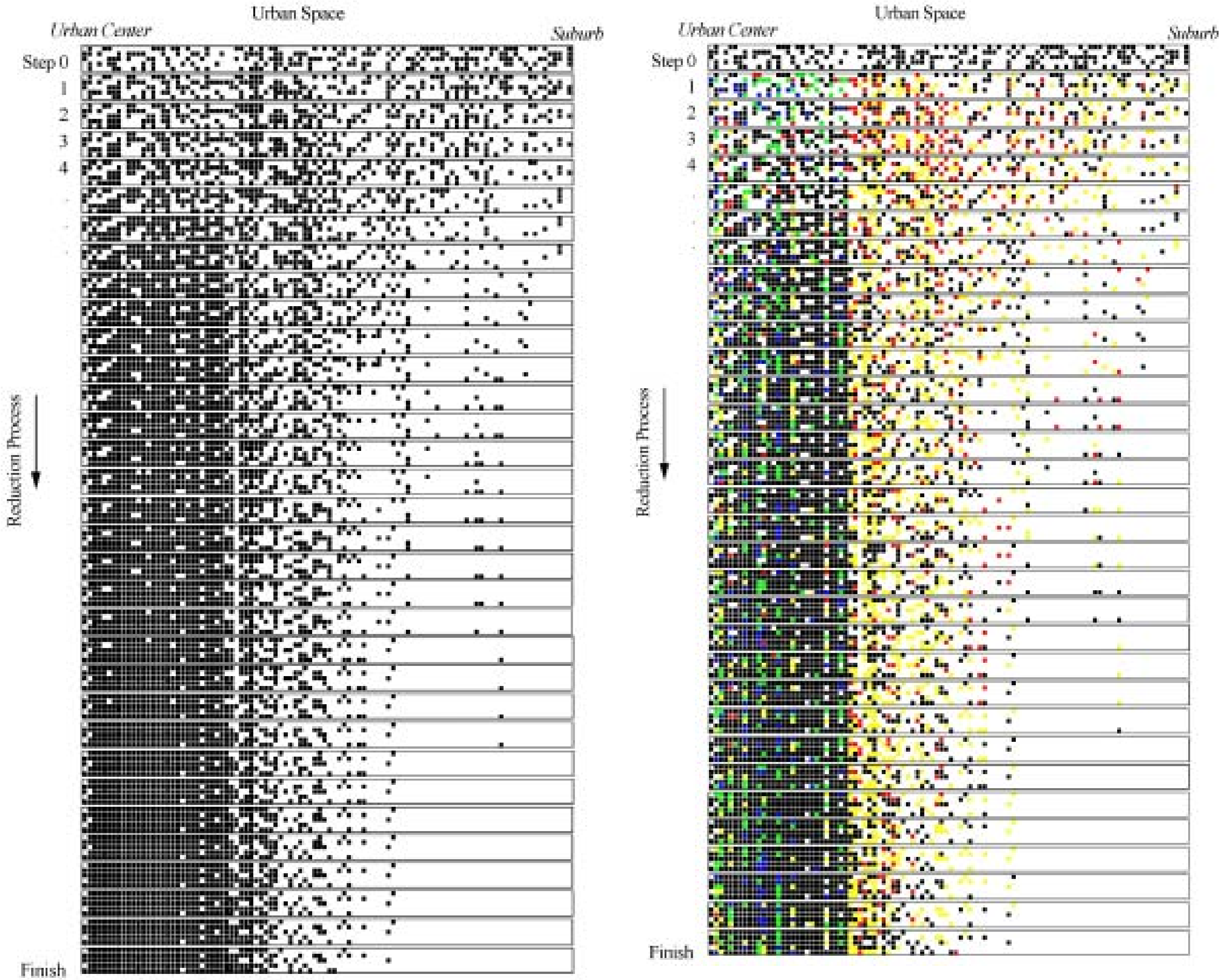

Fig.8 Housing Arrangement and Behavior-selection resulted in previous study

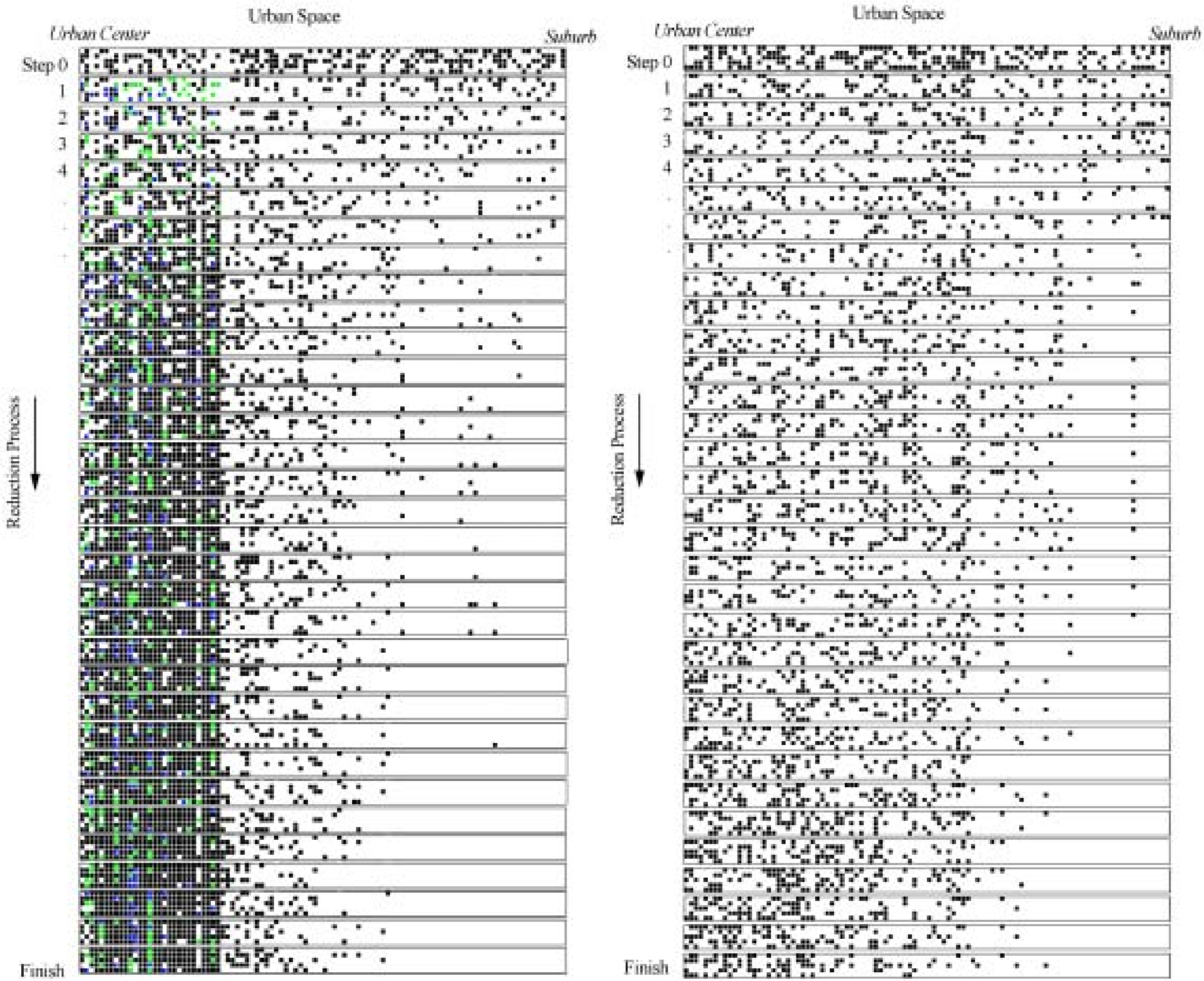

Fig.9. Distribution of Defective Behavior (Left: previous study; Right: Current study)

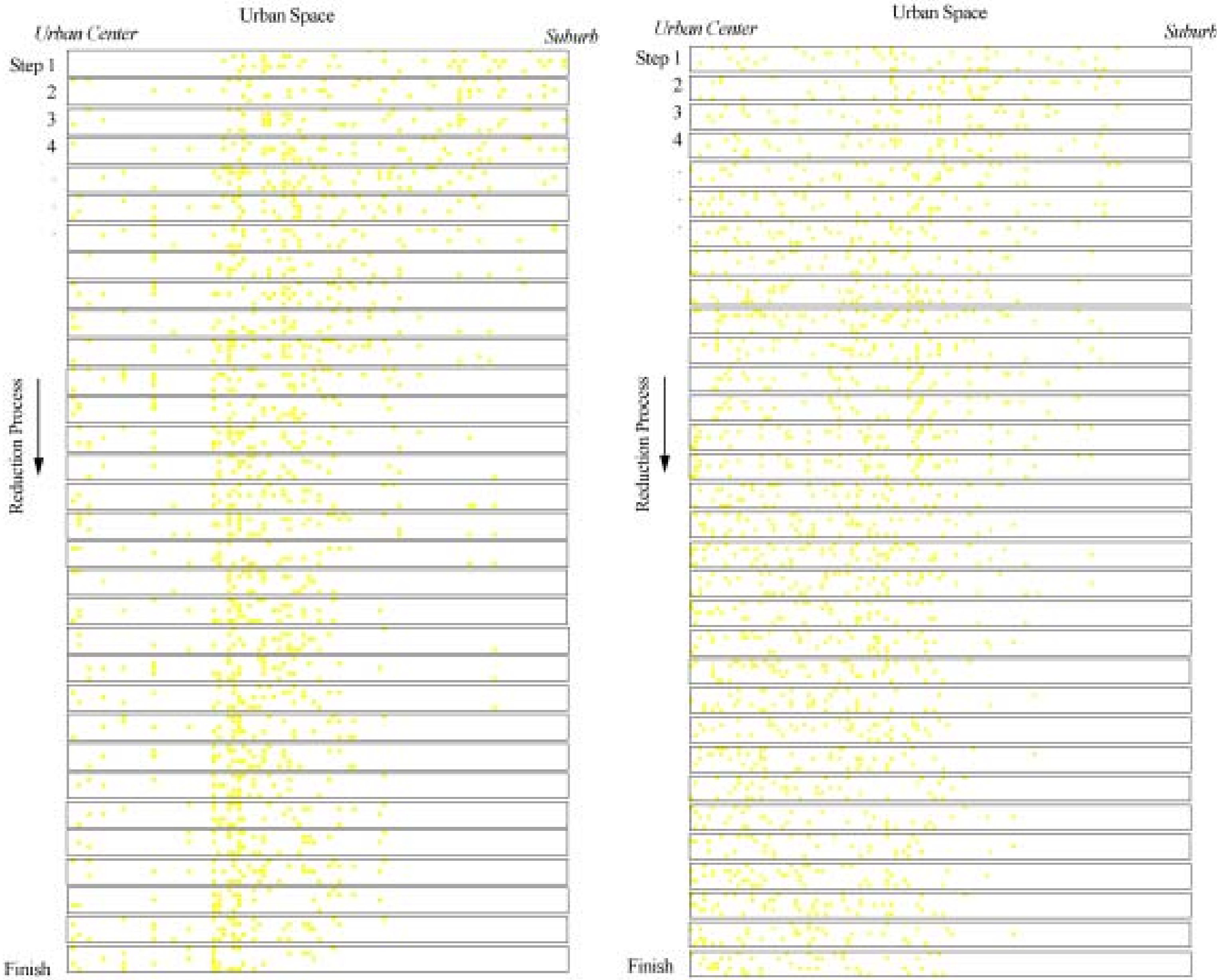

Fig 11

Distribution of Energy-saving (Left: previous study; Right: Current study)