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Carbon Market Risk Analysis & Defense based on Hybrid Simulation

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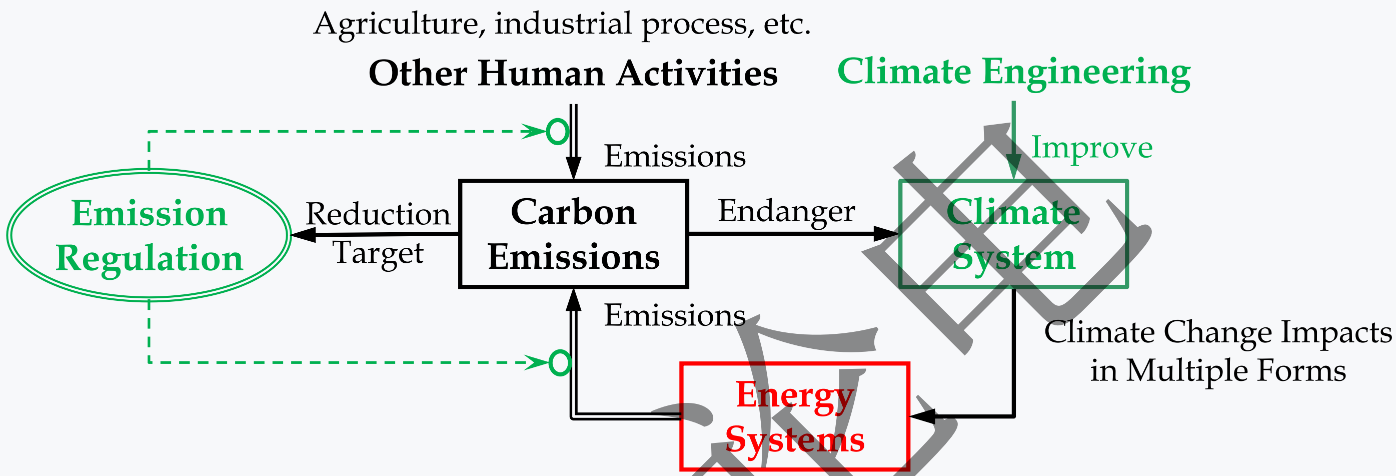
OUTLINE

- Emerging Carbon Market Risk
- Carbon Market Hybrid Simulation
- Carbon Market Control Framework
- Conclusion & Discussion

Climate System & Energy System



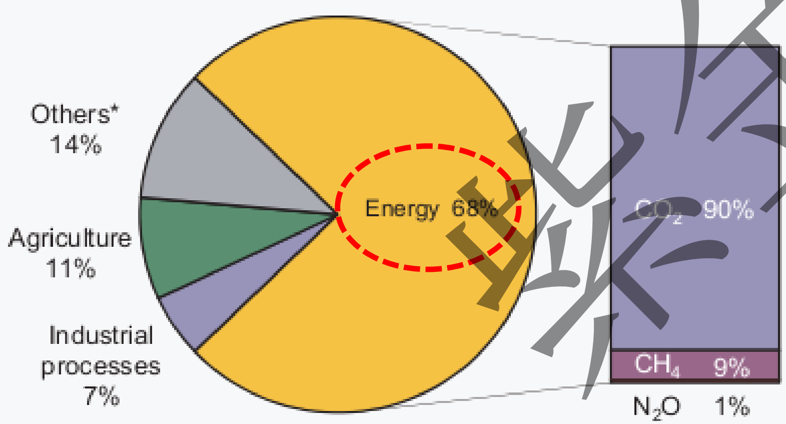


Fig. Estimated shares of global carbon emissions

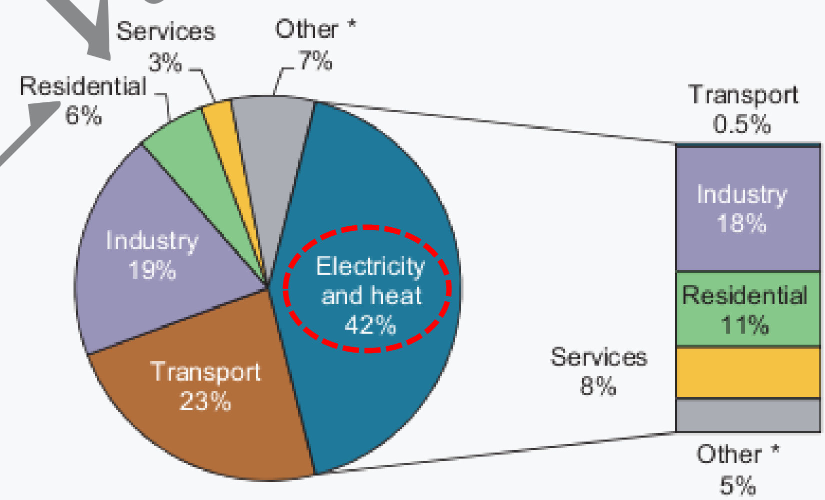


Fig. Carbon emissions from fuel combustion by sector in 2014

Source: CO2 emission from fuel combustion highlights 2016

Carbon Constraints at Different Scale

Global Climate Constraints

- Global Temperature Rise Constraint – "2℃ Target"
- Global Cumulative Emission Constraint - "The Carbon Budget"

Spatial Decomposition

Under "Paris Agreement", each party submitted its INDC (Intended Nationally Determined Contributions)

Long-term National Target

"INDC of China" (by 2030)

- *peak emissions around 2030*
- *increase share of non-fossil fuels in primary energy consumption to around 20 percent*
- *reducing CO_2 emissions per unit of GDP by 60 to 65 percent below 2005 level*

Time Decomposition

The long term target is decomposed into staged targets and implemented by "five year plan"

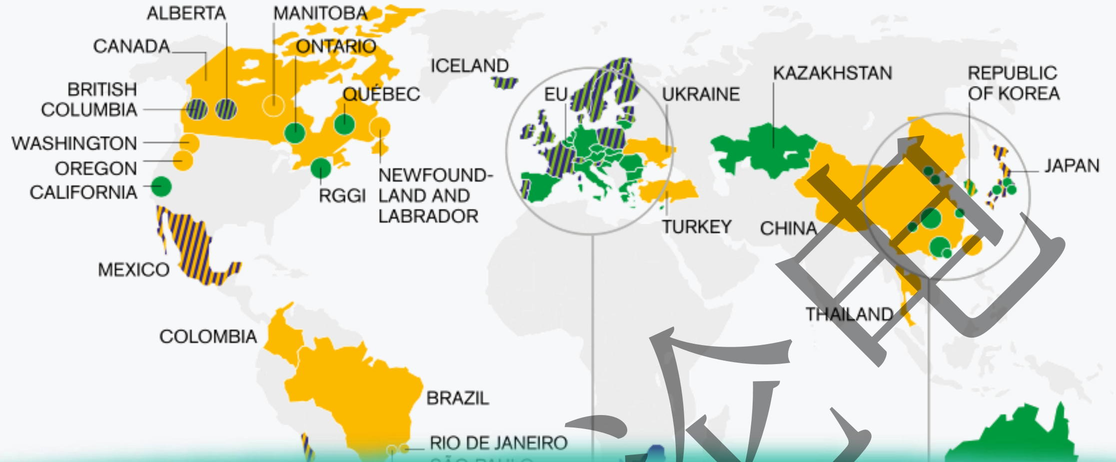
National Target by Stages

"The 13th five-year plan for energy development" (2016-2020)

- *reducing CO2 emissions per unit of GDP by 50 percent below 2005 level (18 percent below 2015 level)*

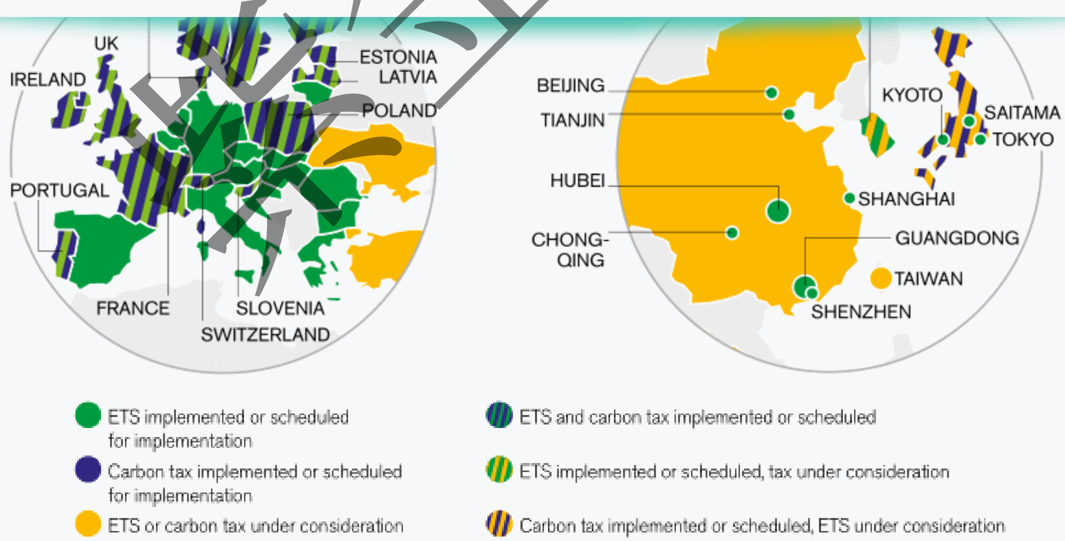
Effective policy instruments are needed

Carbon Pricing as the Major Policy Option



40 national jurisdictions and over 20 cities, states and regions

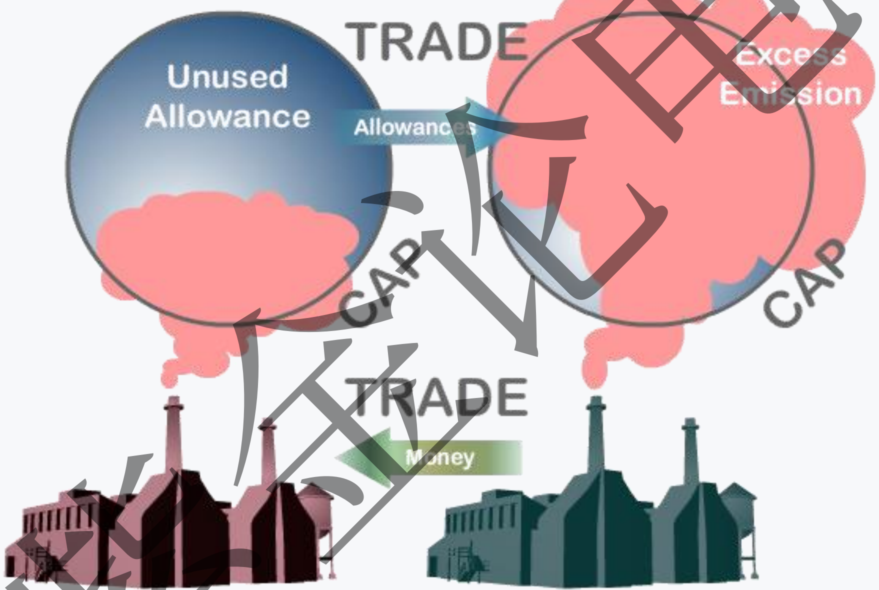
Carbon tax and Carbon market



"cap and trade"

Carbon market

the most preferred carbon pricing mechanism



Cap : a emission upper limit set by government authority , allocated to each emitter (allowance)

&

Trade : emitter can trade allowance among each other, and the carbon price is determined by the supply-demand balance

The Fast Developing Chinese Carbon Market

from sub-national pilots to a national ETS

Pilots in two provinces (Hubei and Guangdong) and five cities (Beijing, Tianjin, Shanghai, Chongqing, and Shenzhen) since 2013

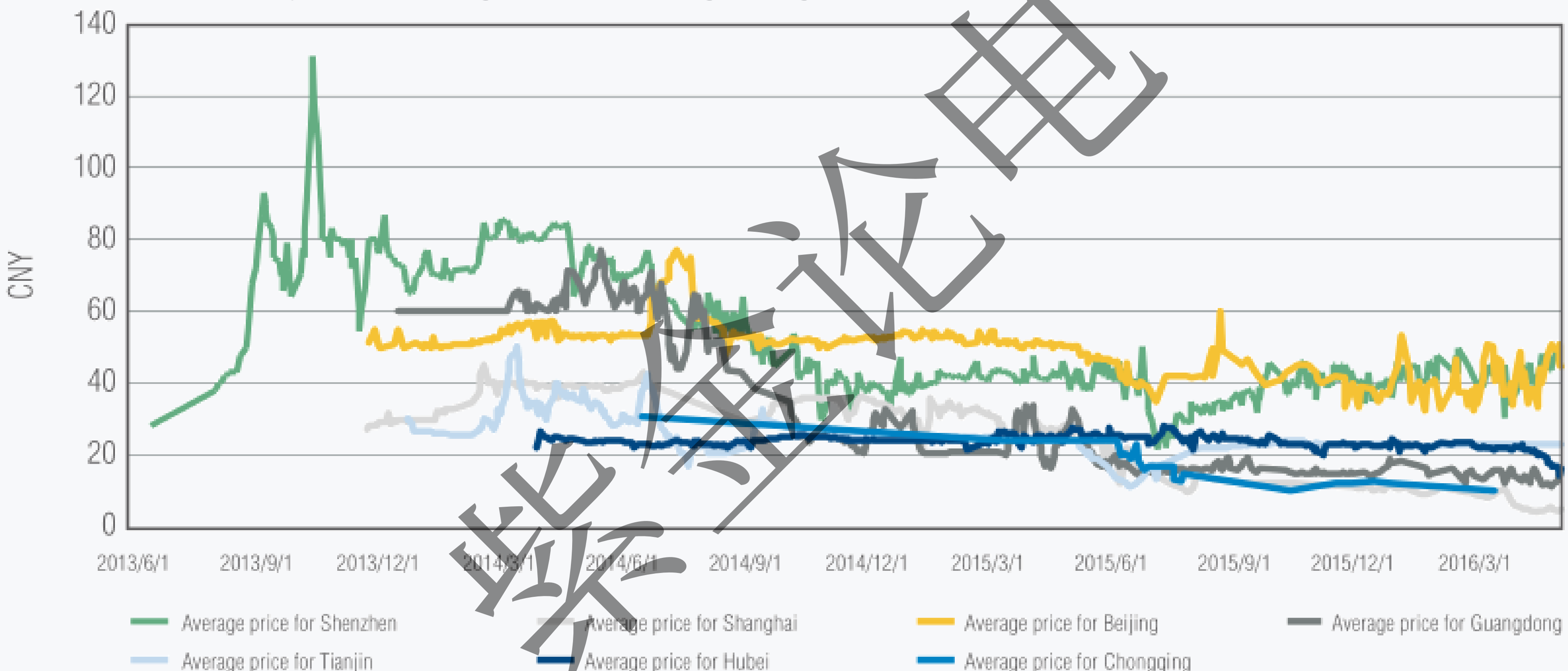


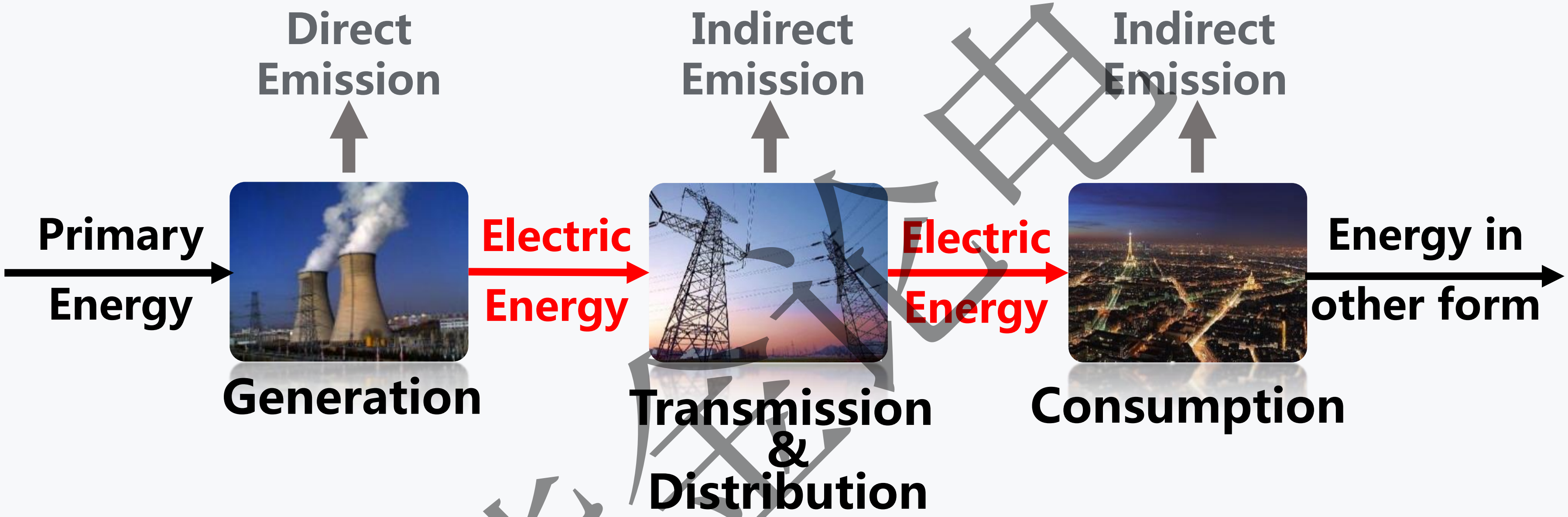
Fig. Price Dynamics of pilot carbon markets in China

Source: Carbon Markets Almanac, ICIS, 2016

A national ETS since 2018

Power Industry in Pilot Carbon Markets

constraints for power generation, transmission and utilization



Main area for carbon emission reduction
Major participants in carbon market

Effective Ex-ante Analysis Method

the key to risk assessment and management

Demand: high exogenous volatility

Supply： inelastic, determined by authorities

Effective Ex-ante Analysis Method & Tool

- What is the consequence if different disturbances occur?
- How to coordinate between environmental and economic efficiency?

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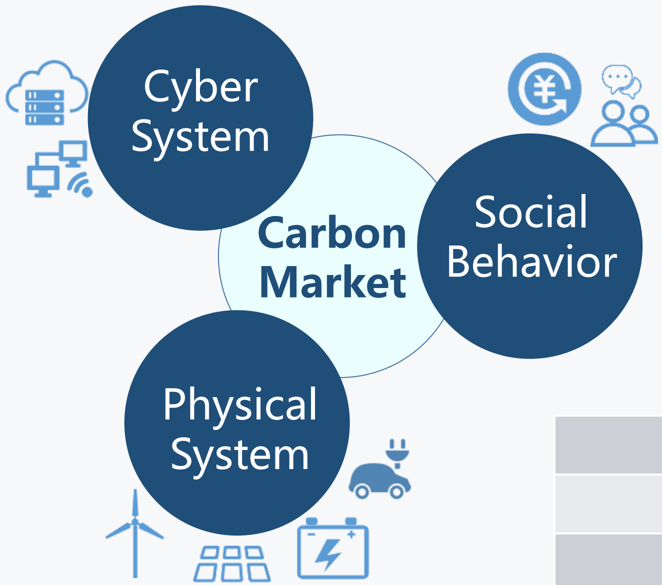
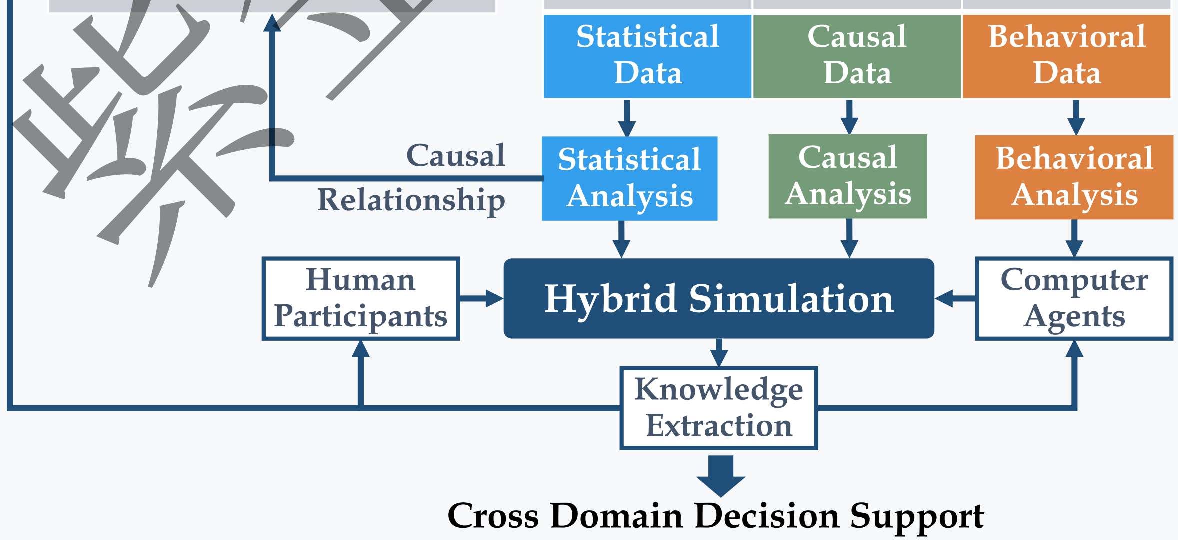
The Complexity of the Target Problem

human behavior involved macro-energy problem



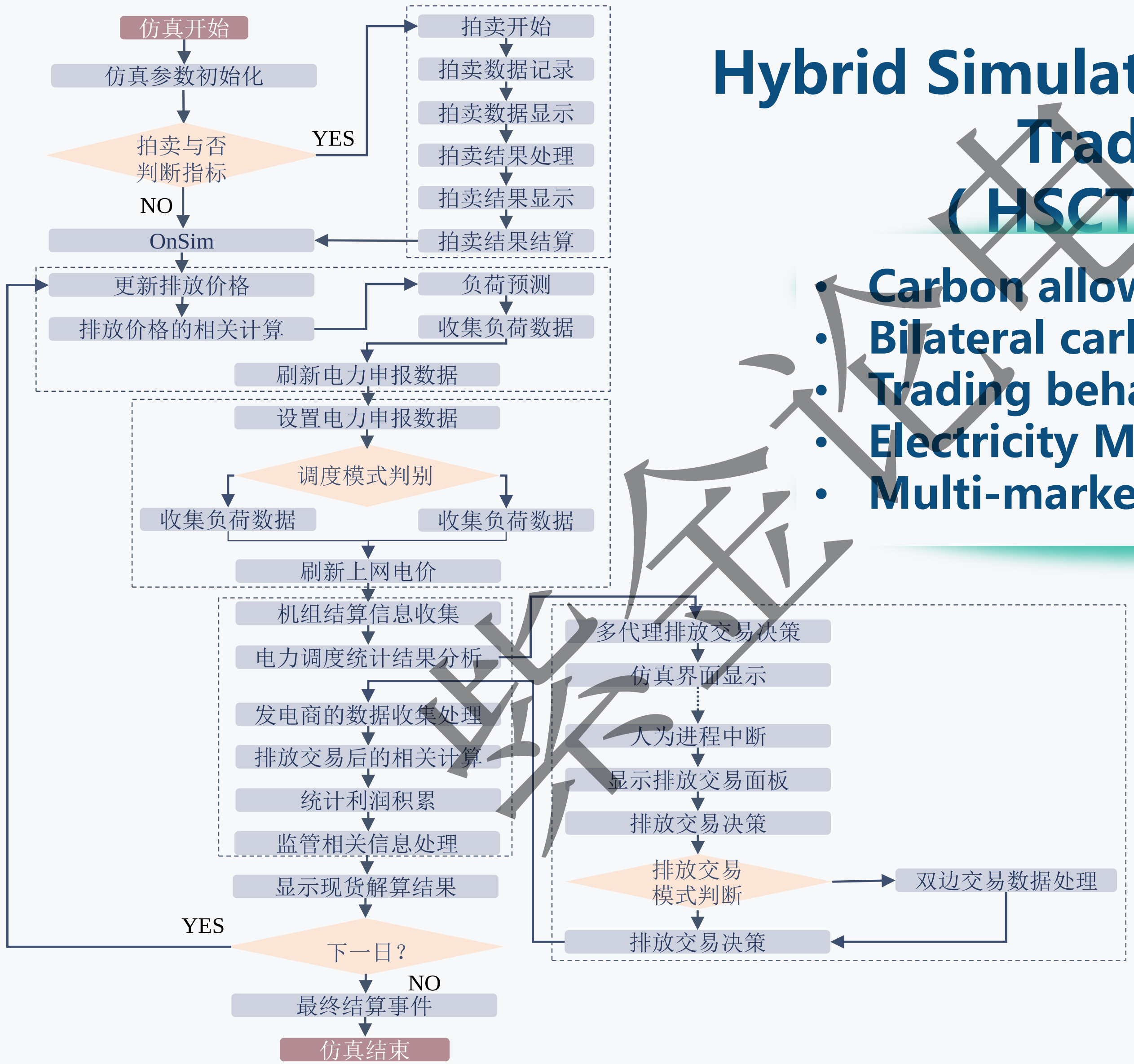
- Objective Physical Laws
- Empirical Statistical Laws
- Subjective Human Behaviors

	Statistical Data	Causal Data	Behavioral Data
Questionnaires	√		√
Data Collection	√		√
Documents	√	√	
Experiments/Simulations	√	√	√
Mathematical Models	√	√	



Hybrid Simulation of Carbon Trading

based on DSMES (Dynamic Simulation platform for Macro-Energy Systems ）



Hybrid Simulation of Carbon Trading （HSCT）V1.0

- Carbon allowances auction
- Bilateral carbon trading
- Trading behavioral agents
- Electricity Market
- Multi-market clearing

Hybrid Simulation of Carbon Market Software

hybrid simulation of human participant and computer agent

Human-machine interface

Supports 1000 computer agents or 10 human participants to participate hybrid simulation

Micro Trading Behavior Modeling

construct behavior agent based on human-subjected experiments

Behavior modelling – the key to market simulation

- **Introduce human to the simulation**
- **Model authentic computer agent**

Step 1. Key driving factors extraction

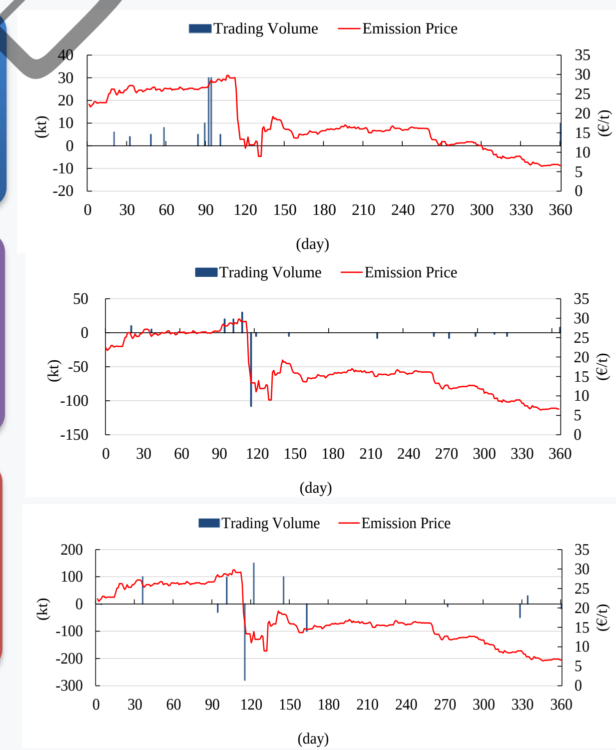
- Historical data mining can utilize existing big data technology
- Determine the mathematical form of driving factors

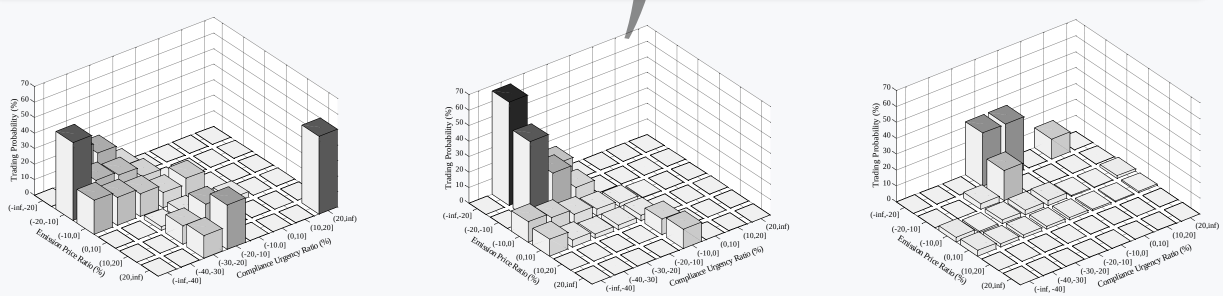
Step 2. Sample collection and quantitative analysis

- Behavior samples obtained through human subjected experiments
- Quantitative relationships between decision-making behavior and driving factors

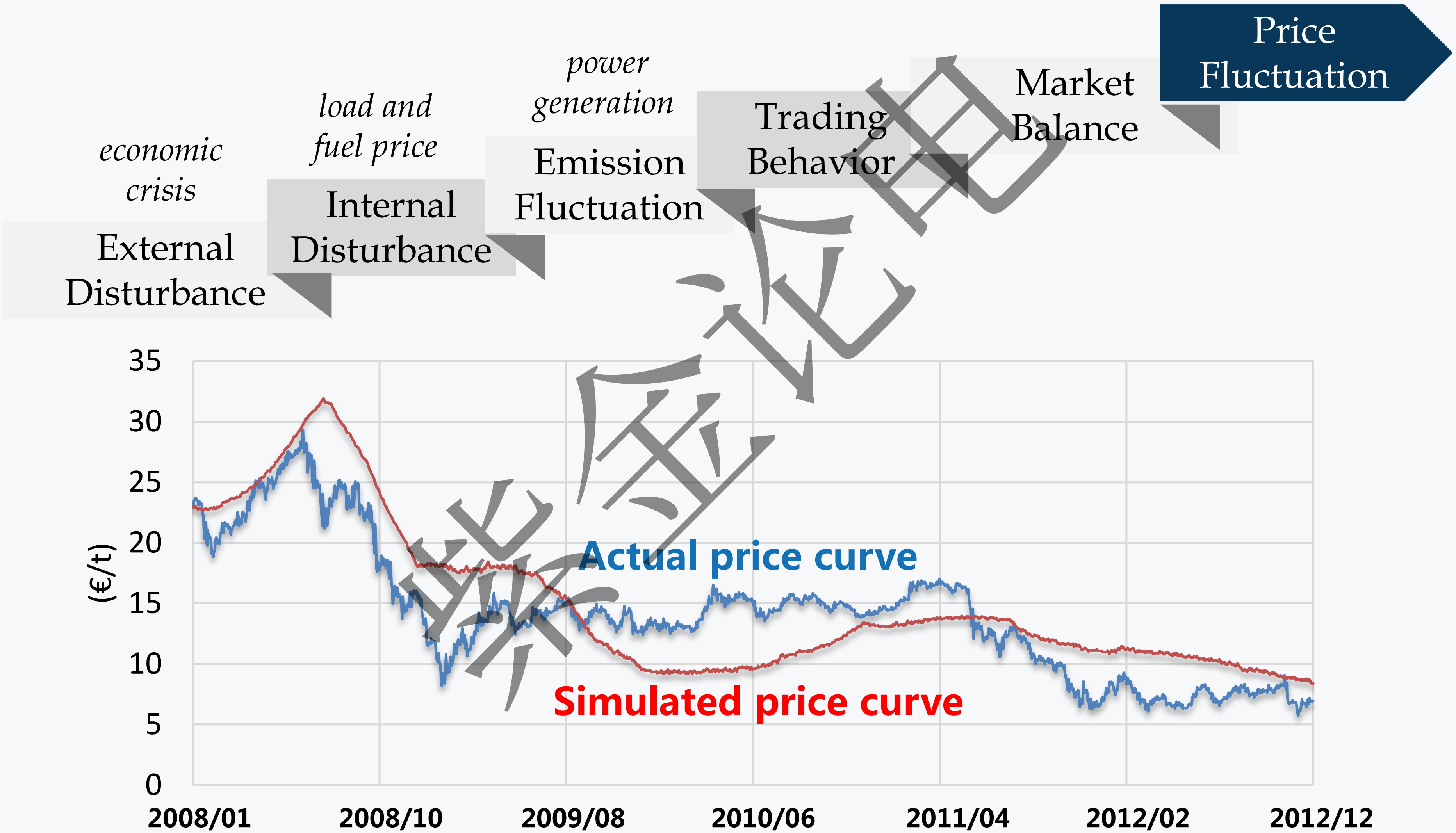
Step 3. Behavior agent modelling and validation

- Decision-making model is constructed based on quantitative analysis results
- Validate the computer agent model to ensure its effectiveness





Validation of the simulation tool



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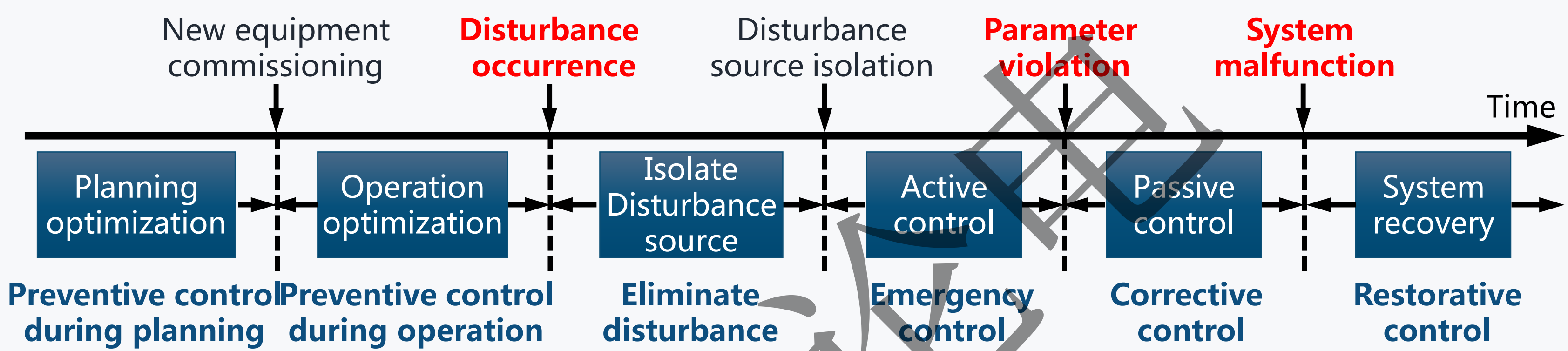
The General Framework of Disaster Defense

lessons learned for power system blackout defense system

The general framework of disaster defense

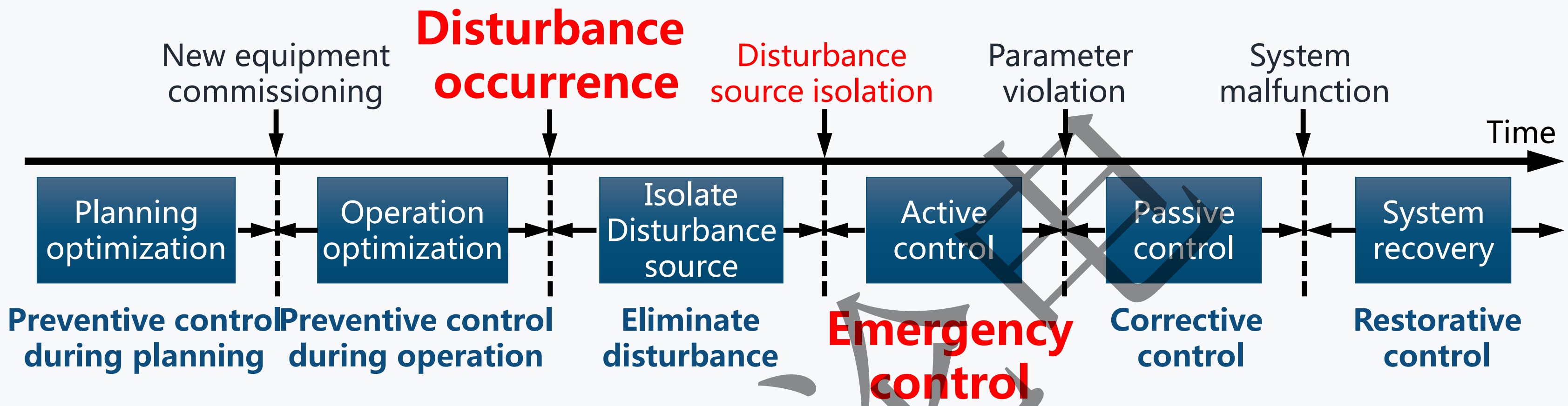


A multi-defense-line framework for carbon market can be designed by identifying key events

Preventive control	*market design and operation optimization before the occurrence of disturbance*
Emergency control	*when disturbance occurs, the feedforward control before the disturbance impacts emerge*
Corrective control	*the feedback control after the impacts emerge (parameter violation) and before the market malfunction*
Restorative control	*function restoration after the malfunction*

The Defense Framework of Carbon Market

identification of market disturbances



- **from economic system :** During the financial crisis and debt crisis in Europe, demand for emission allowance dropped significantly
- **from natural system**： Carbon emissions caused by wildfires in California are estimated to be 120 million tons, meanwhile significantly reduce the forest carbon absorption capacity over the long term
- **from cyber system :** In January 2011, EU ETS suffered a serious cyber theft of allowances worth more than 50 million euros, the trading system was forced to shut down

Key task for preventive & emergency control

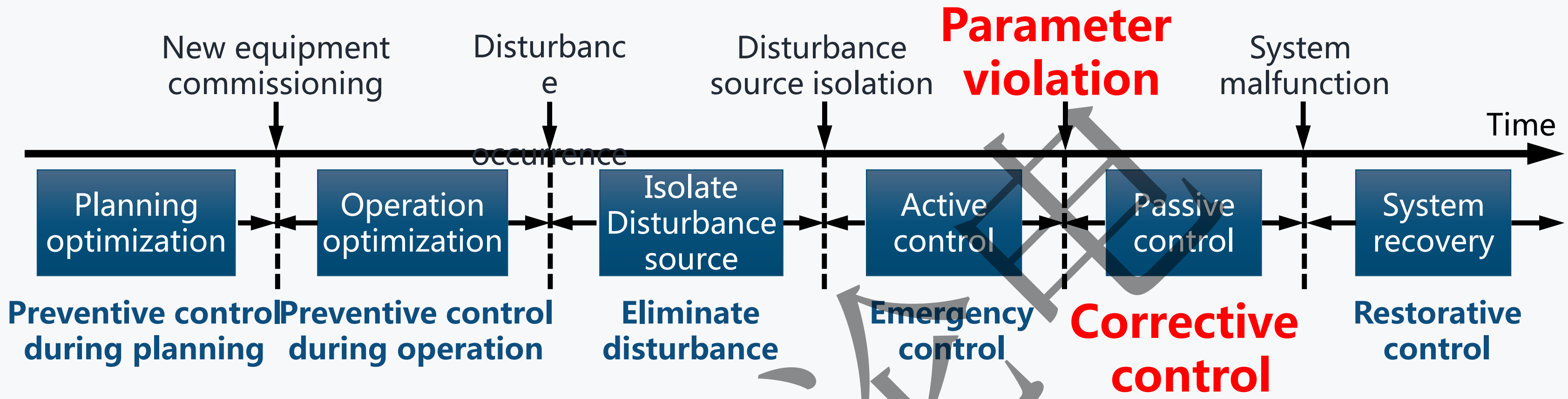
identification and analysis of different potential disturbances

to optimize market design & operation

Example of disturbance source isolation: freezing the accounts involving in malicious market manipulation

The Defense Framework of Carbon Market

market monitoring during operation



- **The "cap" in carbon market is a time section constraint for cumulative emissions at the end of a given compliance period**
- No explicit emission constraint during market operation (price constraint exists)
- If emergency control is not adequate, corrective control should be activated ASAP, rather than wait till the market malfunctioned

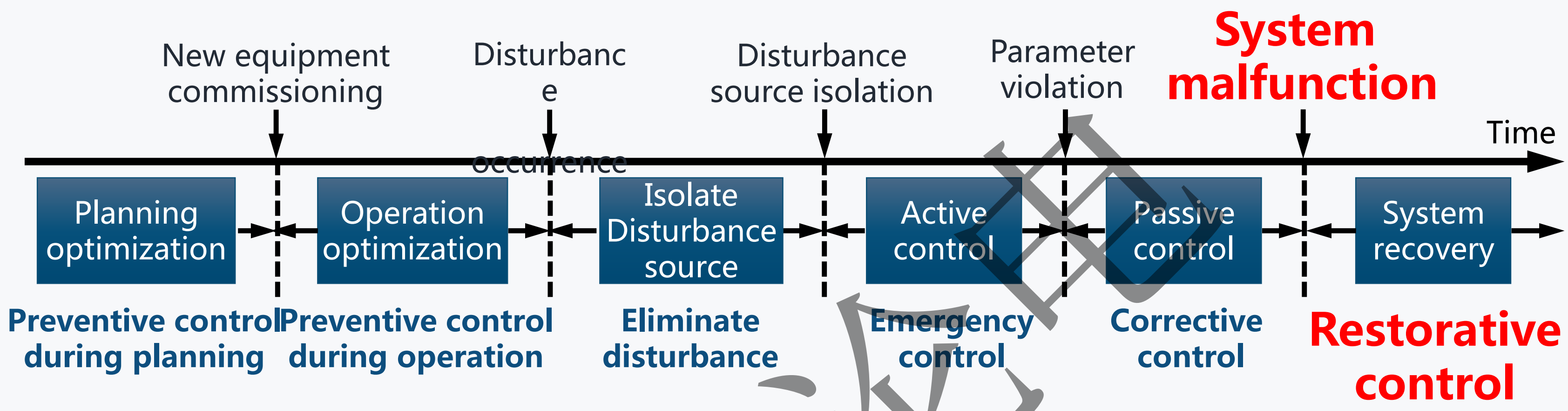
Key task for corrective control

design emission monitoring indicators during operation

to aid corrective control

The Defense Framework of Carbon Market

parameter monitoring during operation



- **Malfunction of carbon market** - carbon emission quantity (or intensity) exceeds the pre-set limit for a given compliance period
- For some extreme situations, not cost-effective to stick to the pre-set limit
- Restore the function of the carbon market at the following phase

Key task for restorative control

quantitative evaluation of excessive emission damages

Carbon Market Risk Management

"cost+risk" minimization problem under given constraints

Social cost ↓ Residual risk ↓

$$\min \sum_{t=1}^{T} C(\mathbf{X}_t) + R^e$$

$s.t.$

$\mathbf{G}(\mathbf{X}_t) = 0$ Equality constraint

$\mathbf{Z}'(\mathbf{X}_t) \le 0$ Inequality constraint

Disturbance probability ↓ Social damage ↓

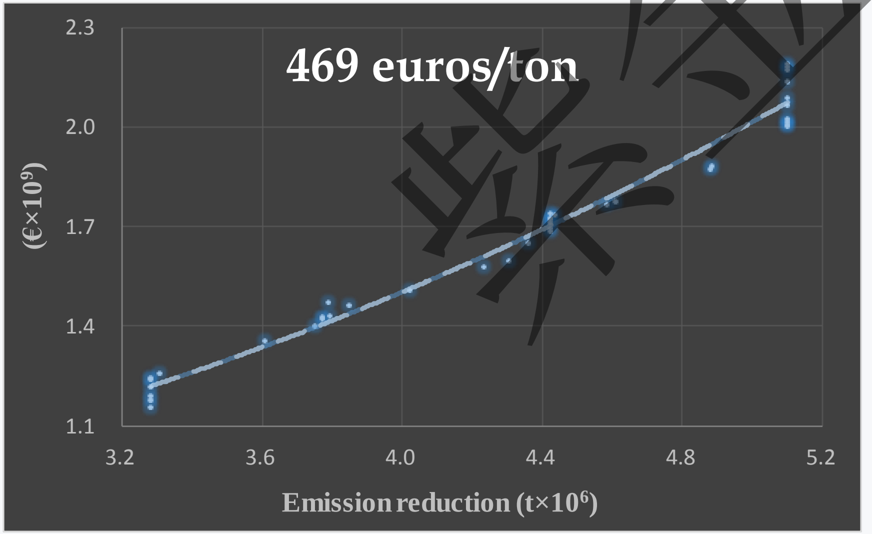
$$R^e = \sum_i P_i \times D_i^e$$

controversial to evaluate the social damage caused by excess carbon emission

Marginal social control cost ↓

$$R^e = \sum_i P_i \times \Delta Q^e \times C_i^e$$

↑ Excess Emission Quantity



use marginal social control cost to evaluate excess emission risk

Driving factors behind this price collapse

- excess supply of emission allowance
- significant drop of emission allowance demand

Emission intensity reduction outcome is not sufficient as a result of the carbon price collapse. A stable carbon price is necessary to stimulate low carbon technology.

Control measure

reduce allowance supply in the carbon market

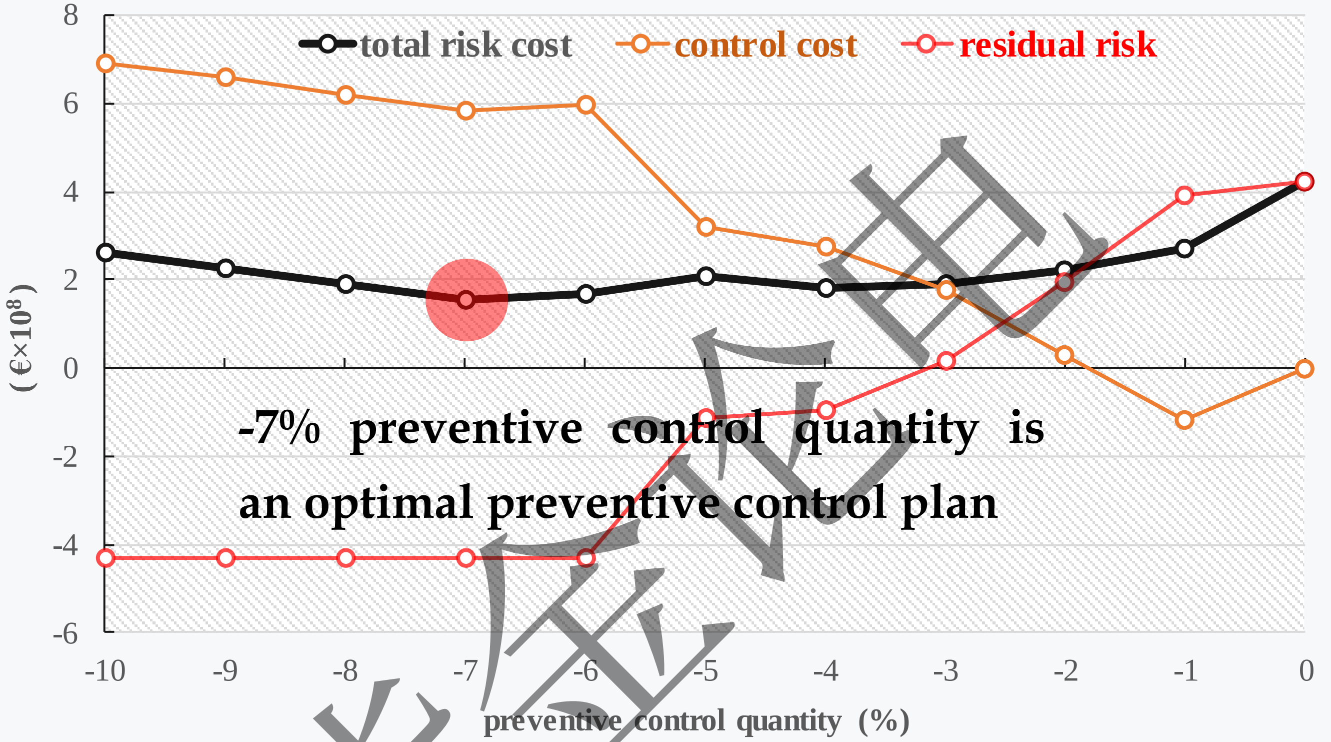
preventive control – initial allowance allocation **before disturbance**

emergency control – adjust allowance supply **after disturbance**

- **1st case: for deterministic disturbance**
  - preventive and emergency control, respectively
  - coordination between preventive and emergency control
- **2nd case: for single probabilistic disturbance**
  - coordination between preventive and emergency control
- **3rd case: for multiple probabilistic disturbances**
  - coordination between preventive and emergency control

1st case: for deterministic disturbance

preventive control optimization



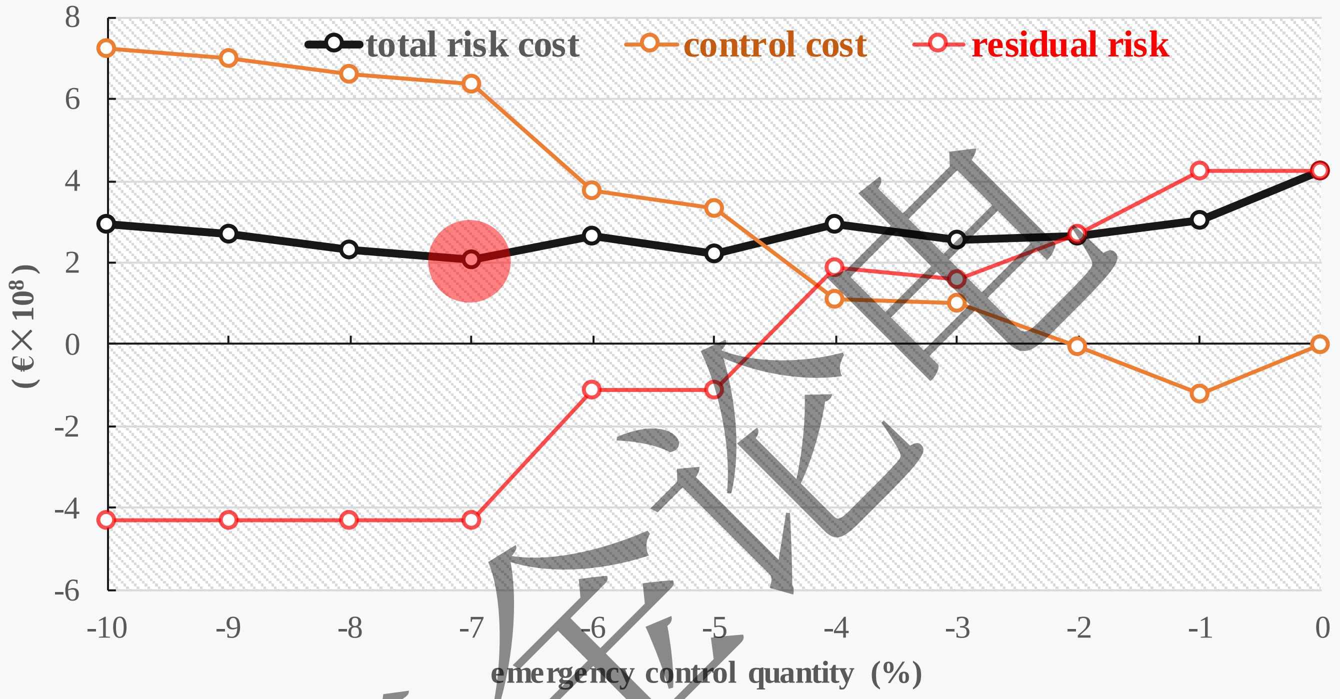
Residual risk =
probability * (intensity outcome – intensity target) * generation quantity * marginal social control cost

Control cost =
cost for market regulator + generation companies + end users

Total risk cost = control cost + residual risk

1st case: for deterministic disturbance

optimization of emergency control



-7% emergency control quantity is the optimal preventive control plan ，but with higher total risk cost

Here， -7% control means ***buying 7% allowance （compared with the overall supply）from the market by the market regulator***

1st case: for deterministic disturbance

coordination between preventive and emergency control

	The total risk cost (€×10^8) of emission control under different emergency control										
preventive control (%)	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10
0	4.24	3.03	2.67	2.57	2.94	2.22	2.66	2.08	2.31	2.71	2.93
-1	2.73	2.49	2.77	2.59	2.48	2.54	2.21	2.35	2.64	2.97	
-2	2.21	1.94	1.93	2.09	2.42	1.98	2.22	2.60	3.15		
-3	1.91	2.17	2.09	2.49	1.85	2.10	2.59	2.87			
-4	1.80	2.06	2.35	1.87	2.11	2.46	2.87				
-5	2.07	2.28	1.76	2.09	2.45	2.80					
-6	1.67	1.73	1.88	2.51	2.85						
-7	**1.55**	2.01	2.40	2.82							
-8	1.89	2.35	2.80								
-9	2.29	2.42									
-10	2.62										

optimal coordinated control ：-7% preventive control

- *no coordination space between preventive and emergency control*
- *for deterministic disturbance, the earlier you control, the better effect you get*

2nd case: for single probabilistic disturbance

coordination between preventive and emergency control

What about probabilistic disturbance?

Scenario A probability（%）	Optimal coordinated control		Total risk cost（€×10^8）
	Preventive control（%）	Emergency control（%）	
0	/	-7	-1.10
10	/	-7	-0.78
20	/	-7	-0.46
30	/	-7	-0.15
40	/	-7	0.17
50	/	-7	0.49
60	/	-7	0.81
70	/	-7	1.13
80	-2	-2	1.44
90	-3	-4	1.66
100	-7	/	1.55

certainty

For lower probability disturbance
emergency control

For those in between…
coordinated control

For deterministic disturbance
preventive control

3rd case: for multiple probabilistic disturbances

coordination between preventive and emergency control

In real world, we should prepare for all sorts of potential disturbances, even conflicting ones…

Scenario A probability （%）	Scenario B probability （%）	Optimal coordinated control plan			Total risk cost of emission control （€×10^8）
		Preventive control （%）	Emergency control （%）		
			Scenario A	Scenario B	
100	0	-7	/	17	1.55
90	10	-7	/	17	-0.53
80	20	-7	/	17	-2.60
70	30	-7	/	17	-4.68
60	40	-7	/	17	-6.76
50	50	-7	/	17	-8.84
40	60	-7	/	17	-10.91
30	70	-8	/	18	-13.02
20	80	-8	/	18	-15.15
10	90	-9	/	19	-17.37
0	100	-10	/	20	-19.59

Optimal coordinated control can be calculated by ex-ante simulation analysis

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Conclusion

For micro-behavior-involved macro energy problems

- *a knowledge extraction platform is constructed by integrating the causal data (based on mathematical models), the statistic data (with non-causal relationship), and the behavioral data of (human participants)*

Engineering techniques adopted to analyze and manage carbon market risk

- *Simulation method, tool*
- *and a multi-defense-line control framework*

"All models are wrong, some are useful" --- George Box

Related Publications

- Jie Huang, Yusheng Xue, Chao Jiang, Fushuan Wen, Feng Xue, Ke Meng, Zhaoyang Dong. An experimental study on emission trading behaviors of generation companies. IEEE Transactions on Power Systems, 2015, 30(2): 1076-1083

- 蒋超,薛禹胜,黄杰,等.基于实验经济学仿真构建碳排放交易的多代理模型[J].电力系统自动化,2014,38(17):80-86. DOI: 10.7500/AEPS20140807005.
  JIANG Chao,XUE Yusheng,HUANG Jie, et al. Modeling Multi-agent in Carbon Emission Market Based on Experimental Economics Simulations[J].Automation of Electric Power Systems,2014,38(17):80-86. DOI: 10.7500/AEPS20140807005.

- 黄杰,薛禹胜,蒋超,等.碳市场风险的分析与控制：(一)框架设计[J].电力系统自动化,2018,42(12):11-18. DOI: 10.7500/AEPS20180214002.
  HUANG Jie,XUE Yusheng,JIANG Chao, et al. Carbon Market Risk Analysis and Control Part I Framework Design[J].Automation of Electric Power Systems,2018,42(12):11-18. DOI: 10.7500/AEPS20180214002.

- 蒋超,薛禹胜,黄杰,等.碳市场风险的分析与控制：(二)沙盘推演[J].电力系统自动化,2018,42(14):1-7. DOI: 10.7500/AEPS20180214004.
  JIANG Chao,XUE Yusheng,HUANG Jie, et al. Carbon Market Risk Analysis and Control: Part II Sand-table Simulation[J].Automation of Electric Power Systems,2018,42(14):1-7. DOI: 10.7500/AEPS20180214004.

Thanks for your attention！