The Simulation and Management of Adaptive Smart Grid Oriented Power Mix based on Evolutionary Dynamic Mechanism under High Percentage of Renewable Energy Policy

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***Abstract*--On the basis of evolutionary economics & adaptive control theory, this study tries to develop an integrated energy resource portfolio, applying the concept of smart grid, to provide the following functions: (1) accommodating supply-side, demand-side and regulating resources, (2) dynamically balancing supply and demand, and (3) coping with the challenge of climate change.**

To perform dynamic multi-agent system (MAS) empirical simulations, we further accommodate the following variables: (1) state variables, (2) measurement variables, (3) performance variables and (4) control variables, and the mutual relationship and interactions of the variables from the feedback mechanism.

The results of the simulation under various scenarios are: (1) adaptive electricity demand, (2) adaptive self-organized non-linear path dependence for smart grid energy resources portfolio, (3) adaptive reserve capacity for evolutionary power resource planning & assets management, (4) adaptive electricity prices, which can be served as references of decision-making for the planning and management of electric power system.

I. INTRODUCTION

The characteristics as well as challenges and uncertainty of energy resources for power system could be described by varietal factors, such as economic variables, load fluctuations, prediction errors, promotion of power supply projects and scheduling changes, occasional incidents, pollution controls, fuel price fluctuation, electricity price changes, technology development, and policy changes. Along with that, the increase of renewable energy due to policies of non-nuclear and low-carbon has casted significant uncertainty the planning and operation of power system, and thus initiate the need of adaptive and flexible power system resource planning and operation.

To flexibly manage the demand requires accurate load forecast of renewable energy resources, and mastering of their load characteristics; what equally important is the availability of regulating capability, such as fast-start gas units, demand-side management, demand response, power storage system, electric vehicles, and other ancillary services and interconnected networks. In short, smart grid coupled with real-time pricing can effectively integrate, schedule and dispatch diversified energy resources, systematically or/and regionally. Accordingly a robust and adaptive power system, as well as reliable, safe and stable, smart low-carbon power system, can be formed, to cope with the complexity and uncertainty of the future.

In general, it is a combination of control factors, which includes technology advancement, market driving force, policy promotion, and operation with business model. By applying measured variables and performance indices, we can grant optimal dynamic portfolio control for energy resources under real time, real location and real scenario, so as the balance, reliability, safety, efficiency, and low-carbonization of power supply and demand can be maintained.

To meet the fundamental characteristics of power supply and demand described above, this study tries to apply the second law of non-equilibrium thermodynamics on energy balance principle, evolutionary dynamics and adaptive control theory as the theory foundation. The complement infrastructure conditions includes: (1) adaptive power resource planning & dispatching, (2) instantaneous on-line adaptive capability under smart-grid framework in the future, (3) accommodating the 3E (energy, economy and environment) objective and current national energy development policy into adaptive control. To verify the design concept of the said, this study develops a simplified model and applied it to system dynamic modeling tool of the control theory, and conduct empirical simulation.

II. CONCEPT DESIGN OF ADAPTIVE SMART-GRID POWER SUPPLY AND DEMAND RESOURCE PORTFOLIO

A. Literature Review

This study mainly refers to literature that covers evolutionary economics and system science (and their derivative field: adaptive control, complex science, non-equilibrium thermodynamics of dissipative structure, system dynamics simulation and so forth). These studies that link to electric economics are also included.

In the field of evolutionary economics, literature includes: biological evolution, technological evolution, institutional evolution, co-evolution, firm evolution (microeconomics), economic evolution (macroeconomics), evolutionary game theory, pattern evolution, web evolution and others. Yang argued the reasonableness of the usage of biological metaphor [11]. In “Interview with Professor Hodgson”, institutional evolution was discussed from the point of view related to experimental economics and evolutionary game, and thoughts on the co-evolution of technology and institution were also mentioned [12]. Dopfer studied evolutionary economics in three different scales: microscale, mesoscale and macroscale [20]. Simmie et al. compared the difference between technology evolutions of wind power in Germany and the United Kingdom [32]. Cecere discussed the process of transformation and dramatic change of eco-innovation under the co-evolution of technology, institution, enterprise and society from the perspectives of lock-in and path dependence [19]. Tedeschi et al. explored the transformation patterns and behavior of technological change from the point of dynamic evolution of innovative network [33]. Chang criticized the simplified and limited view of mainstream economics from the point of dynamic evolution of causal relationship between institution and economic development [6]. Jia compared the differences of attributes on models of the abduction and retroduction with traditional deduction and induction methods in economics about the structure, form, logical reasoning, strengths and restriction [14].

In system science, Ioannou wrote a tutorial for adaptive control which covered continuous, discrete and nonlinear adaptive control [25]. Widrow extended adaptive control to adaptive inverse control using signal processing approach [34]. Mainzer presented the idea of complex thinking which linked complex system to evolution of material, evolution of life, evolution of mind and brain, evolution of computability and evolution of artificial life and artificial intelligence from the computational dynamics for matter, mind and mankind [26]. Holland proposed adaptive subject of complex adaptive systems, hidden order of the "emergence" and the computational simulation of echo model [23]. Wordrop wrote a popular science on "Complexity", covering the "emergence science" at the edge of order and chaos [35]. Rammel explored the management of "complex adaptive system" of nature resources from the point of co-evolution [31]. Haghnevis investigated the model structure of complex adaptive system [22]. Nobel Prize winner, Prigogine first introduced an open system with life. Under the condition of being away from equilibrium, the system is able to maintain the ordered structure via the self-organization of matter and energy. It's called dissipative structure [29]. Meadows et al. proposed updated version of their well-known book "Limits to Growth." They classified four kinds of finite growth dynamic models: asymtotic growth, S-curve growth, oscillation after over-growth and collapse after over-growth [27]. Botterud proposed a system dynamic simulation model for long-term investment decisions in a deregulated electricity market [18].

Last but not least, in the field of electric economics including prediction, planning, dispatch, smart grid, environmental economics (carbon trade, climate change), eco-economics, and sustainable development. Chen et al. established an electrical load forecasting model, and further developed a decision support system [9]. Chung et al. established an electricity programming model and analyzed the mitigation policy: the effect of suppressing CO2 emission on economic development [16]. Ingham et al. investigated mitigation and adaption under climate change considering the learning effect in uncertainty [24]. Chang establishes a multi-objective programming 3E (energy, economy, environment) model and connected it with I-O analysis and scenario simulation method. The programmed output maximizes the value-added of industry, minimizes the cost of power generated, minimizes the amount of CO2 emission and other desired optimization objectives we want under the considerations of fuel for power generation, power generation capacity, equilibrium of electricity supply and demand, unit commitment for peak/ off-peak load, reliability and other limitations we face in reality. The established 3E model was used to study the issue "The Optimal Renewable Energy Structure for Sustainable Energy Development" [5]. Hung et al. constructed a regional integrated resources planning model under consideration of smart grid. This model helps to analyze the evolution of energy resources portfolio [2]. Chang et al. constructed a unit commitment model considering the steam, combined cycle gas and pump storage power generators, and develop an information system for it. [4]. Hung et al. conducted carbon asset planning to promote solar photovoltaic of carbon trading plan [1]. Hung et al. studied the effect of climate change on electricity system and policy of adaption [3]. Huang explored the distribution, flow and change of energy in urban eco-economic system from the point of view of emergy evaluation [10]. Rammel discussed the evolution policy under sustainable development from the point of adaptive elasticity [30].

B. The Research Framework

1) Background and Evolutionary Economics Theory

In the face of the pressure resulting from the greenhouse effect and sustainable development, many theoretical ideas regarding business model and application tools were brought into existence. While environmental economics emphasizes the internalization of environmental externalities, it is still fundamentally based on and subject to neo-classical economic theory and limitations, that is, from the standpoint of an economist to govern the economic system according to equilibrium theory. Under this situation, resources and the environment are regarded as exogenous factors of economic systems. It is therefore a weak model for sustainable development. On the other hand, ecological economics attempts to integrate the ecosystem and the economic system and to observe interaction and feedback between these two systems from a systematic viewpoint. Under this situation, because the resources and environment are endogenous factors, the system can be classified as a medium sustainable development model. In addition, the circular economics is based on an ecological economics view of regional economics, from a practical viewpoint of the 3R's of resource reduction, recycling and reuse, further strengthening the periodic and feedback nature of ecological economics, as well as its microscopic and realistic characteristics, i.e., from the circular economics point of view to deal with ecological and economic systems. Under this circumstance, its sustainable development model has moved forward. Finally, evolutionary economics is from the interaction of ecosystem and economy system arising from emergence of co-evolutionary point of view, further strengthening the system's development & balance dynamic and adaptive characteristics, i.e., from the evolutionary economic viewpoint to deal with the economy system and ecosystem, which is more towards strong sustainable development.

Compared with the neoclassical economics which is based on (1) static equilibrium, profits maximization and rationality (2) constant assumptions of preferences, technology and institution (3) simplified point of view of reductionism, determinism and mechanistic theory, the evolutionary economics emphasizes (1) the pursuit of dynamic equilibrium, satisfactory solution and bounded rationality (2) given the dynamic evolutionary mechanism for preferences, technology and institution (3) the holism, the random theory and the organic theory under the point of view of complexity. The areas it covers include (1) technological evolution (2) institution evolution (3) economic evolution (4) frim evolution (5) industrial evolution (6) evolutionary game (7) culture evolution (8) social evolution and (9) network evolution, etc. [7]

This article aims to integrate the "evolutionary economics", "dissipative structures thermodynamics", "evolutionary dynamics" and "adaptive control theory" via the system dynamic simulation analysis embedded by the positive and negative feedback mechanisms to interpret the co-evolutionary behavior of energy resources portfolio for the smart grid based "complex adaptive systems" in the face of uncertainty. The relevant theoretical basis include:

1. Evolutionary Economics: Extracting each school of neo-classical economic implications of the inherent essence of evolution, including the institutional evolution of the institutional school, technological evolution of the innovational school, mechanism evolution of the regulated school, social evolution of the Austrian school, it absorbs the metaphor of biological evolution and firm evolution combined with systems theory, complexity science and non-equilibrium dissipative structure theory under the open system to shape a new paradigm of dynamic economic development theory.
2. Dissipative structure thermodynamics: An open system via matter and energy exchange by self-organized mechanism to maintain the system structure in order far from equilibrium.
3. Evolutionary Dynamics: Under anti-reductionism it highlights the irreversible characteristics, novelty, path dependence and the dynamic properties of the behavior evolution.
4. The adaptive control theory: Taking into the consideration of internal and external changes of uncertainties, then through the measurement and the estimation, it will flexibly adjustment the system structure parameters by the feedback dynamically to achieve optimal control for the system.
5. Complexity Science: Through the nonlinear interaction between the components of the system, the emergent properties will arise from the dynamic system. The scope includes system science (systems theory, information theory, cybernetics), self-organization theory (theory of dissipative structures, synergetics, catastrophe theory, super cycle theory, chaos theory, fractal theory) and the network complexity.
6. System Dynamics: Via the positive and negative feedback internal mechanism, it will be coupled with stock, flow and auxiliary variables to show the evolution behavior of dynamic system.

2) The Research Process

In summary, from the coupling relationship between the theoretical basis and the characteristics of energy resources portfolio, the paper aims to build up the overall concept design & the construction of a simplified model, then to do the case-scenarios modeling and simulation results interpretation. Accordingly, it would propose the power economic implications for the adaptive energy resources portfolio planning and the management. The research process is shown in Figure 1:

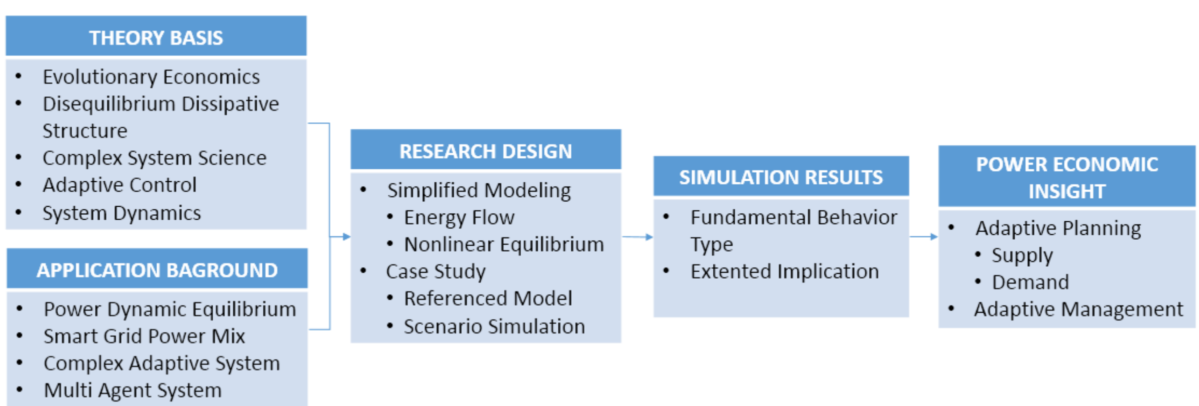


Figure 1. The Research Process

C. Adaptive Control Theory

1) Adaptive Control Theory Basis

The theories of relativity, evolution and control are the three great human inventions in the 20th Century, of which the control theory has been widely applied to engineering control, economic control, social control, and ecological control. The evolution and development of the control theory is originated from classical control (frequency domain control), modern control (time domain control) to intelligent control (smart control). Its theoretical foundation consists of optimal control (deterministic), stochastic optimal control (the random interference and measurement error considerations based on stochastic models) and adaptive control (the system structural adaptive considerations based on deterministic and stochastic models). It covers the relationship with the link mechanism of the state variables (X), the measurement variables (Y), the performance (estimated) variables (Z), the control objectives (J), the control variables (U), the environmental disturbance variables (W) and the measurement error variables (V) [17].

a. State function

i. Continuous type

$$\dot{X} = f[X(\theta,t),U(t),t] = A(\theta,t)X(t) + B(\theta,t)U(t) + W(t) \quad (1)$$

ii. Discrete type

$$X(K+1) = A(\theta,K)X(K) + B(\theta,K)U(K) + W(K) \quad (2)$$

iii. Matrix type (energy resources, for example)

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \vdots \\ \dot{X}_n \end{bmatrix}^T_{1xn} = \left\{ \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{n} \end{bmatrix}_{nxn} \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}_{nx1} \right\}^T_{1xn} + \begin{bmatrix} b_1 \\ \vdots \\ b_m \end{bmatrix}^T_{1\times m} \begin{bmatrix} U_{11} & \cdots & U_{1n} \\ \vdots & \ddots & \vdots \\ U_{m1} & \cdots & U_{mn} \end{bmatrix}_{m\times n} + \begin{bmatrix} \theta_1 \\ \vdots \\ \theta_t \end{bmatrix}^T_{1\times t} \begin{bmatrix} W_{11} & \cdots & W_{1n} \\ \vdots & \ddots & \vdots \\ W_{t1} & \cdots & W_{tn} \end{bmatrix}_{t\times n} \quad (3)$$

n= the dimension of state variables for energy resources, including hydraulic, oil-fired, coal-fired, gas-fired, nuclear, cogeneration, wind power, photovoltaic, biomass, demand response, energy efficiency, energy storage and electric vehicles ...... etc.

m= the dimension of control variables for energy resources, including market, technology, policies, systems, business model, and so on.

t = the dimension of disturbance variables for energy resources, including the reliability factors, mitigation factors and adaptation factors ...... etc.

b. Control function

i. Continuous type

$$U(t) = -K(\theta,t)X(t) \quad (4)$$

ii. Discrete type

$$U(k) = -K(\theta,k)X(k) \quad (5)$$

iii. Matrix type

$$\begin{bmatrix} U_{11} & \cdots & U_{1n} \\ \vdots & \ddots & \vdots \\ U_{m1} & \cdots & U_{mn} \end{bmatrix}_{m X n} = - \begin{bmatrix} K_1 \\ \vdots \\ K_m \end{bmatrix}_{m X 1} \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}^T_{1 X n} \quad (6)$$

c. Measurement equations

i. Continuous type

$$Y(t) = C(\theta,t)X(t) + D(\theta,t)U(t) + V(t) \quad (7)$$

ii. Discrete type

$$Y(k) = C(\theta,k)X(k) + D(\theta,k)U(k) + V(k) \quad (8)$$

iii. Matrix type

$$\begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{k1} & \cdots & Y_{kn} \end{bmatrix}_{k\times n} = \begin{bmatrix} C_1 \\ \vdots \\ C_k \end{bmatrix}_{k X 1} \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}^T_{1 X n} + \begin{bmatrix} D_{11} & \cdots & D_{1m} \\ \vdots & \ddots & \vdots \\ D_{k1} & \cdots & D_{km} \end{bmatrix}_{k\times n} \begin{bmatrix} U_{11} & \cdots & U_{1n} \\ \vdots & \ddots & \vdots \\ U_{m1} & \cdots & U_{mn} \end{bmatrix}_{m X n} + \begin{bmatrix} \theta_{11} & \cdots & \theta_{1g} \\ \vdots & \ddots & \vdots \\ \theta_{k1} & \cdots & \theta_{kg} \end{bmatrix}_{k\times g} \begin{bmatrix} V_{11} & \cdots & V_{1m} \\ \vdots & \ddots & \vdots \\ V_{g1} & \cdots & V_{gn} \end{bmatrix}_{g\times n} \quad (9)$$

k= the dimension of measured variables for energy resources, including the supply side, the demand side, the price side and the environmental side ...... etc.

g= the dimension of error variables for energy resources, including the reliability and the validity .... etc.

d. Performance function

i. Continuous type [15]

$$Z = f[X(t),U(t),t] = \phi[X(t_f),t_f] + \int_{t_0}^{t_f} F[X(t),U(t),t]dt \quad (10)$$

$$= X^T(t_f)Q_0X(t_f) + \int_{t_0}^{t_f} [X^T(t)Q_1X(t) + U^TQ_2U(t)]dt$$

$$\begin{pmatrix} H(X,U,\lambda,t) = F(X,U,t) + \lambda^T f(X,U,t) \\ Z = \phi[X(t_f,t_f)] + \int_{t_0}^{t_f} \left[H(X,U,\lambda,t) - \lambda^T \dot{X} \right] dt \end{pmatrix}$$

(Quadratic)

ii. Discrete type

$$Z = E\left\{ X^T(\ell)Q_0(\ell)X(\ell) + \sum_{k=0}^{\ell-1} [X^T(K)Q_1(K)X(K) + U^T(K)Q_2(K)U(K)] \right\} \quad (11)$$

(Quadratic)

iii. Matrix type (online estimation)

$$Z = \begin{bmatrix} \hat{X}_1 \\ \hat{X}_2 \\ \vdots \\ \hat{X}_n \end{bmatrix}^T_{1\times n} = A \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}^T_{1\times n} + \begin{bmatrix} B_1 \\ \vdots \\ B_m \end{bmatrix}^T_{1\times m} \begin{bmatrix} U_{11} & \cdots & U_{1n} \\ \vdots & \ddots & \vdots \\ U_{m1} & \cdots & U_{mn} \end{bmatrix}_{m\times n} + \begin{bmatrix} C_1 \\ \vdots \\ C_k \end{bmatrix}^T_{1\times K} \begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{k1} & \cdots & Y_{kn} \end{bmatrix}_{k\times n} + \begin{bmatrix} \theta_1 \\ \vdots \\ \theta_t \end{bmatrix}^T_{1\times t} \begin{bmatrix} W_{11} & \cdots & W_{1n} \\ \vdots & \ddots & \vdots \\ W_{t1} & \cdots & W_{tn} \end{bmatrix}_{t\times n} \quad (12)$$

iv. Power optimal planning model

$$J = Max \int_0^\infty [U(E_t) - C(S_t)E_t]e^{-\rho t}dt$$

$$\text{s.t} \quad \dot{S}_t \equiv G(S_t) - E_t \quad (13)$$

J: objectives; U: utility; C: energy unit costs; E: energy consumption;
S: energy stocks; G: the available amount of renewable energy;
ρ: discount rate

e. The implications of energy resources portfolio (Figure 2)

a. system unknown parameter vector θ; θ means "the structural parameters of the energy flow for adaptive energy resources portfolio system".
b. disturbance W (t), noise V (t) are random series;. The W (t) means the random disturbance of "adaptive energy resources portfolio systems", including policies & institutions, market & technology and other factors, V (t) is the random error of output variables measurement of "adaptive energy resources portfolio systems" .
c. the purpose is to chose the control function U (t) to optimize the performance Z (U, X, t) under given conditions; U (t) means the control variables of "adaptive energy resources portfolio systems", such as energy policy, economic policy and environmental policy; J (U, X, t) means the objective function of "adaptive energy resources portfolio system", such as GDP, profit, CO_2 emissions ,etc.
d. covering the state feedback control (self-feedback) and output feedback control (external feedback).
e. covering the feedforward and feedback control as well as positive feedback and negative feedback control.
f. including the adaptive reference model control (for example, coupling with 3E multi-objective optimal planning model) and adaptive online estimation (self-tuning) control (such as smart grid architecture).
g. the adaptive control model mentioned above is often assumed to be linear and continuous assumption for the differential equation resolution; however, considering the nonlinear and discrete situation in reality, it needs to be transformed to be the difference equation to deal with under the simulation model (see 3.2 Simplified Model System Dynamics Diagram).

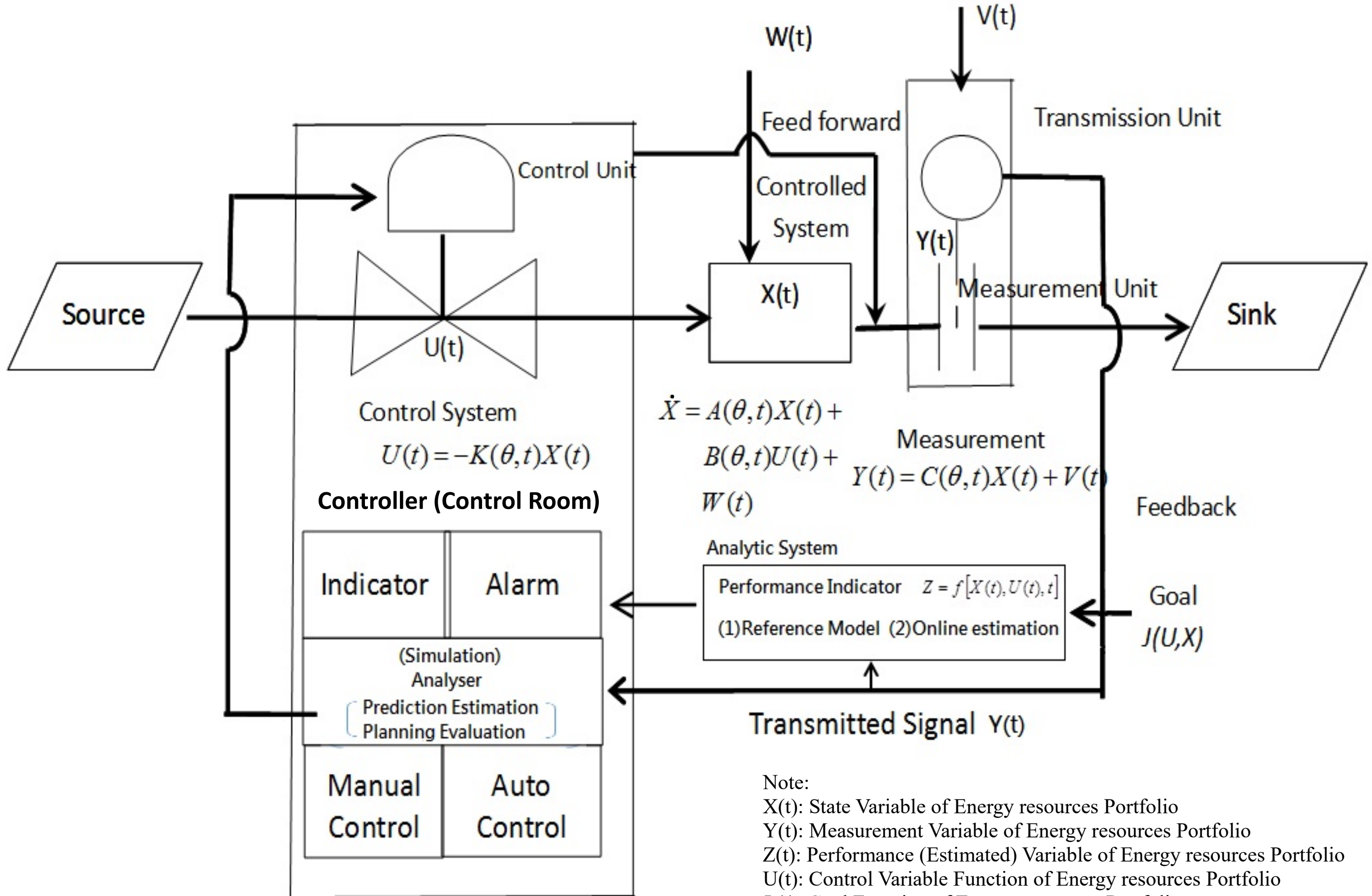
2) General Adaptive Control Modeling and Decision-Making

General control theory extend to the scope of prediction, planning and dynamic simulation, of which prediction and planning belong to feedforward control. Prediction needs to be done by state variable and state function, and planning includes objective function in addition to considering the constraints of state variable and state function, in order to achieve the optimal solution. Control (or Simulation) model includes feedforward control and feedback control (before and after), of which for feedback control, feedback information of state variable or measured variable is used to assess performance index, and using control variable adjustment afterwards to achieve optimal objective. Decision-making is the final synthesis of prediction, planning, and simulation, with evaluations added, as shown in Figure 3.

D. Smart Grid

1) Concept Framework for Power Supply and Demand Balance

Smart grid refers to applying digital technology, integrating advanced power electronics and automated and communication technologies using the grid as the core, optimizing dynamic portfolio for supply-side resources (centralized generation, distributed generation, renewable energy, etc.), demand-side resources (demand-side management, demand response, etc.), regulating resources (energy storage system, electric vehicles, etc.), to establish a power system with a new system framework, operation capability, and optimal asset management capability, towards a robust power infrastructure with even more smart power generation, transmission, distribution, and usage [21]. It can effectively integrate smart low-carbon advanced technologies; energy, environment, economic and technology policy; fuel, power and carbon market; and optimal operation model for power generation, transmission, distribution and sales. It can be readily done under various time, location and scenarios, through observable measured variables (Y) and perceptible performance indices (Z), and adaptive dynamic portfolio control (U), power production, power management, power exchange, and power services related to energy resources (X), in order to ensure power supply and demand balance in response to formidable challenges from future climate change mitigation and adaptation, and lead the country towards smart, low-carbon society development in the future, as shown in Figure 4.



Note:
X(t): State Variable of Energy resources Portfolio
Y(t): Measurement Variable of Energy resources Portfolio
Z(t): Performance (Estimated) Variable of Energy resources Portfolio
U(t): Control Variable Function of Energy resources Portfolio
J (t): Goal Function of Energy resources Portfolio
W(t):Disturbance of Energy resources Portfolio
V(t): Noise of Power Resource Portfolio

Figure 2. Adaptive Control Diagram – Energy resources Portfolio Adaptive System

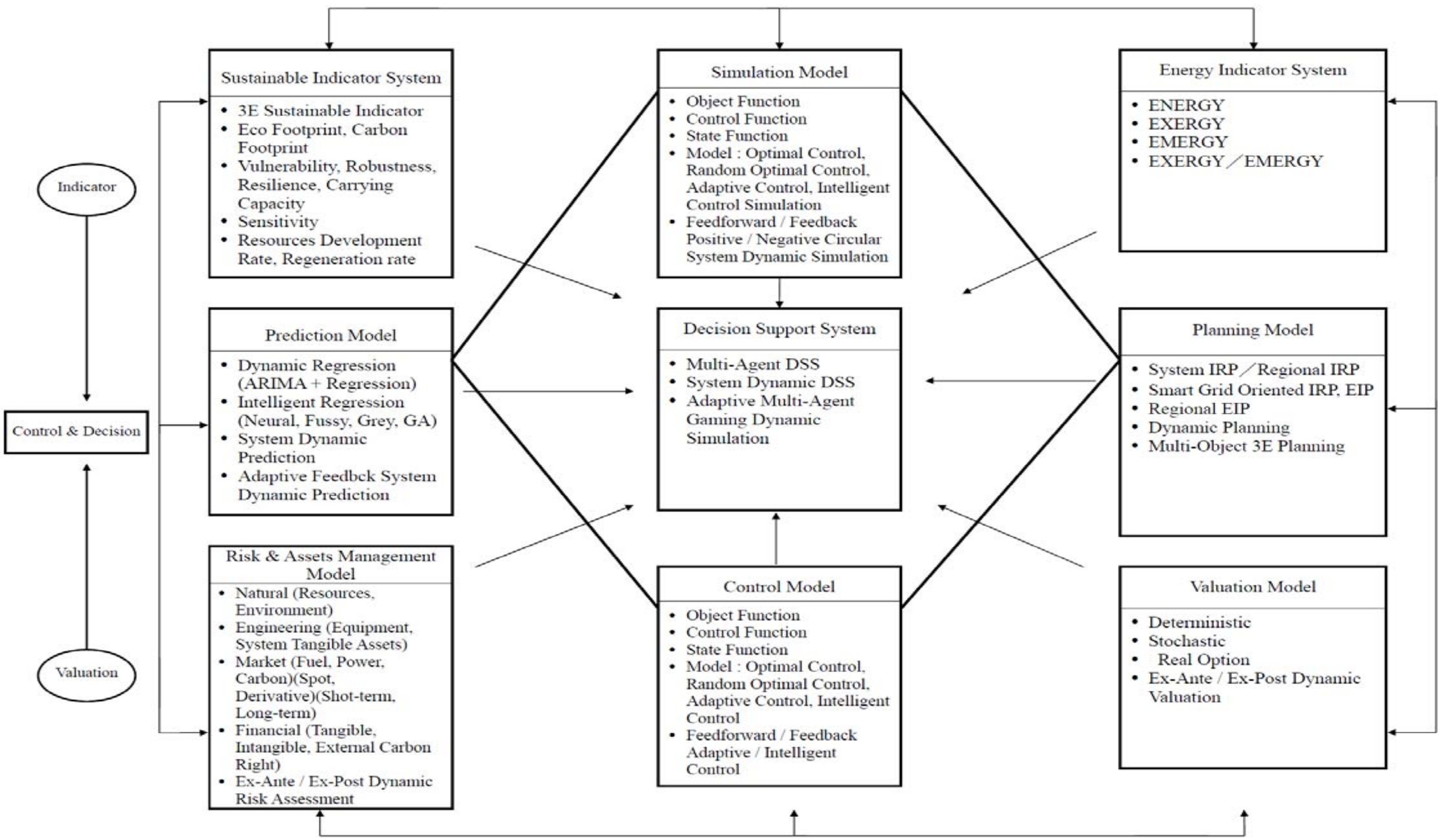


Figure 3. Concept Design for Energy resources Portfolio Adaptive Modeling and Decision-Making Model

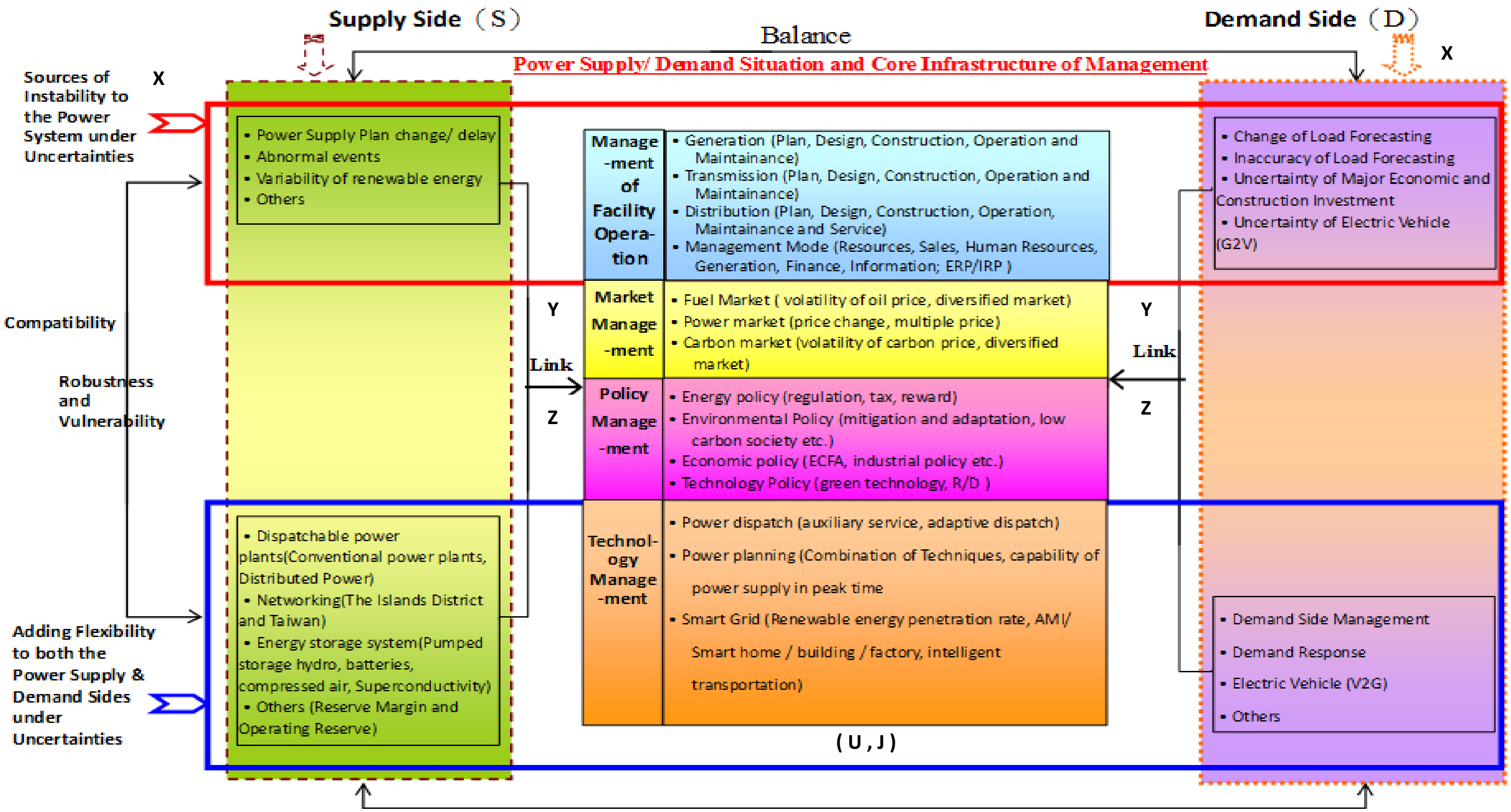


Figure 4. Dynamic Balance Framework of Adaptive Smart Grid Power Resource Portfolio

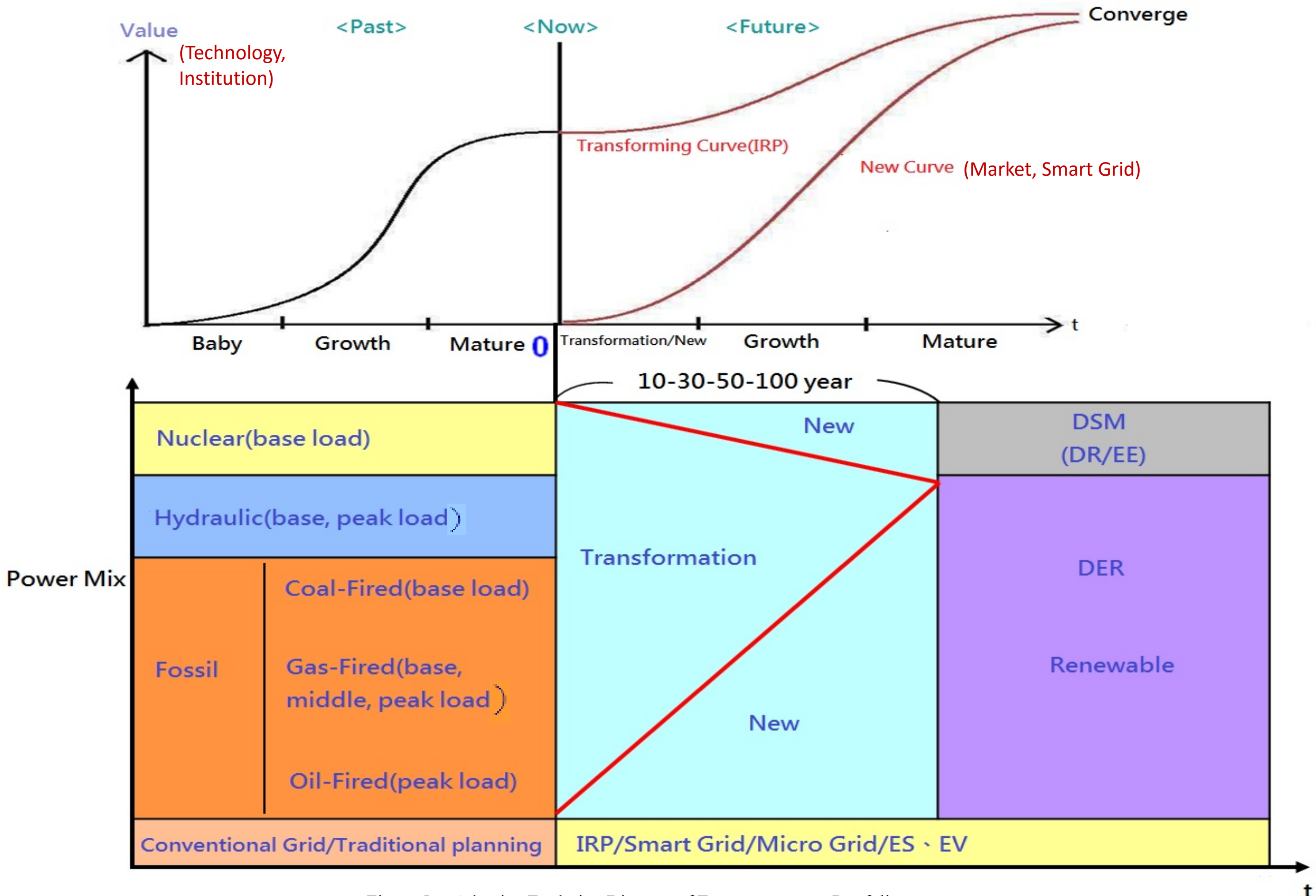


Figure 5. Adaptive Evolution Diagram of Energy resources Portfolio

2) Roadmap and Blueprint for Power Resource Portfolio

Power supply for traditional grid is based on power development plans under planned economy, large-scale power plants including a portfolio of nuclear, thermal (coal, gas, oil), hydro, etc., with centralized generation for base, medium and peak loads. However, with the development of renewable energy, distributed generation, and demand-side management, power systems are moving toward operation model under market economy in the future, with a smart power infrastructure shaped from centralized power and grid and distributed power and grid (micro-grid), with instantaneous adaptive dynamic portfolio and control of energy resources. Through complementary and substitutive portfolio among centralized and distributed power, renewable and non-renewable energy, supply-side and demand-side resources, it can jointly evolve into a smart, low-carbon or zero-carbon power future towards sustainable development. It is the evolution of a dynamic process of S curve function including the transformation from the old to new development curve, as well as including complementarity among resources, technology, market, policy and operational management, creating maximum value for energy resources adaptive dynamics portfolio, as shown in Figure 5.

E. System Dynamics Framework

Basically, under the platform established by the grid hub, power supply, demand, and price will achieve optimal value portfolio of energy resources by Internet of Things, forming a DPSR (driving force-pressure-state-response) bi-feedback circulation of power supply and demand system dynamic mechanism[20]. For power supply, it includes linkage of power supply portfolio structure planning, operation, and management, as well as energy and environmental policy and regulations. For power demand, it includes linkage of power demand and production and demand-side management of residential and commercial users, micro-industrial economics and macro-economics, as well as energy and environmental economic policy and regulations. In terms of price, it includes price setting and adjustment under regulation, and market price fluctuation under liberalization. The three elements establish linkage and mutual feedback, forming a non-linear emergent characteristics (positive & negative feedback) and mechanism of co-evolution system, as shown in Figure 6 [13, 28].

F. Sustainability Index Establishment

The system dynamics model described above integrates with adaptive dynamics of the state variables, measurement variables, performance indices, and control variables, of which the performance indices need to meet sustainable development objectives. Sustainable development indices can be established from driving force-pressure-state-response) multi-feedback, including: (1) energy index – based on Energy, of which EXERGY and EMERGY can be applied, emphasizing energy quality in addition to showing the amount of energy; the former EXERGY is separated by available energy (it can be converted to do the work) from un-available energy (dissipative energy, it can not be converted to do the work) to distinguish energy quality; the latter EMERGY uses solar power as the basic unit, to define the size and quality of various types of energy amount as it is transformed from solar power to user side; (2) value index – based on value, including GDP, green GDP, or other measurements beyond economic characteristics; (3) risk index – relative to value, including operational risk, market risk, financial risk, environmental risk; (4) environmental index (mitigation index) – based on the environment, including ecological foot print and carrying capacity considerations under resources and environmental constraints, as well as carbon foot print of carbon emissions intensity, and extending to water foot print of water resource utilization; (5) adaptation index – consideration the vulnerability, robustness and stability of natural, socio-economic and system sensitivity and resilience; (6) integrated index – sustainability index that considers energy, economy and environment (3E) and mitigation and adaptation.

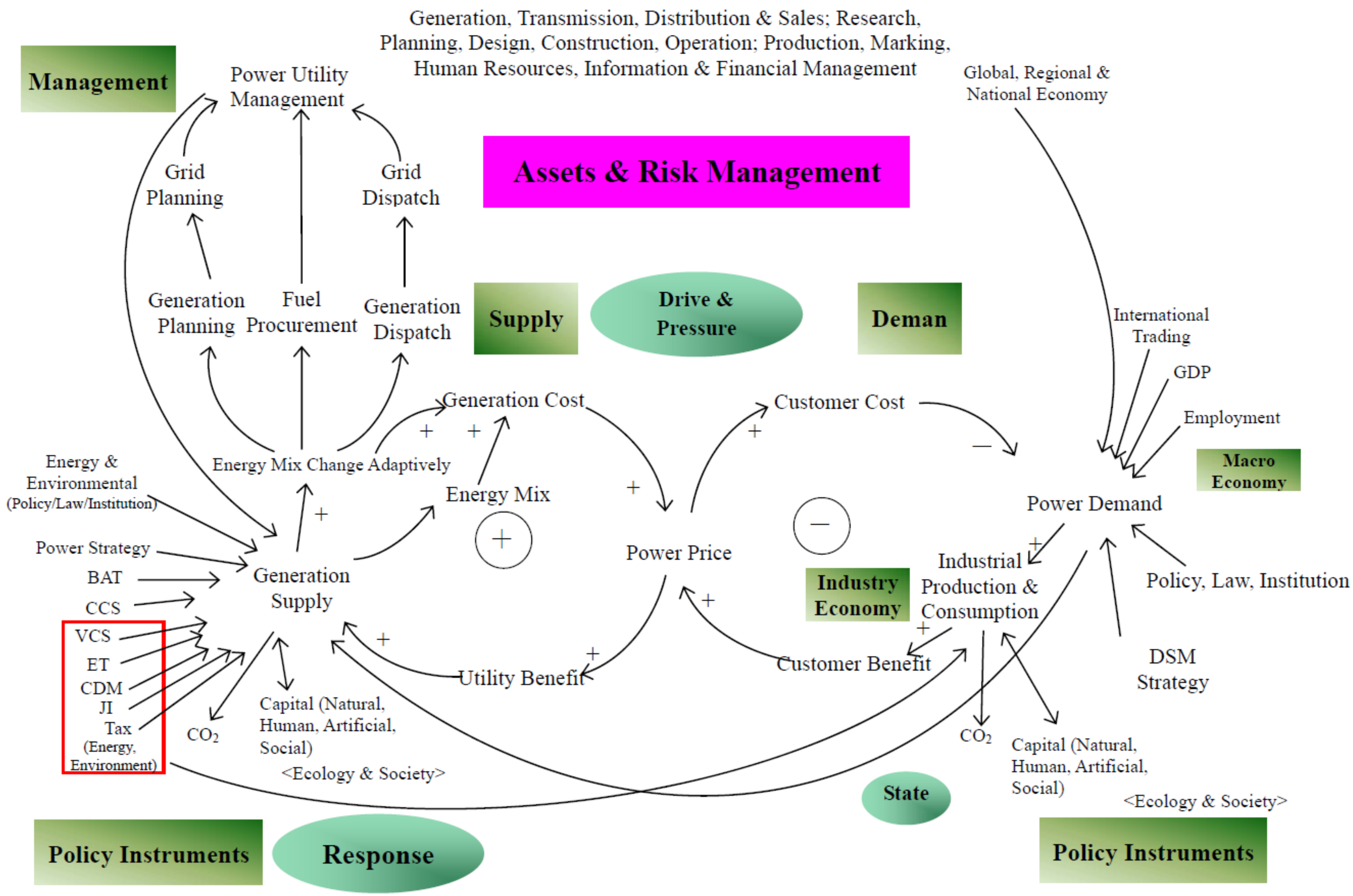


Figure 6. System Dynamics Modeling Diagram of "Smart Grid Energy resources Portfolio Adaptive System"

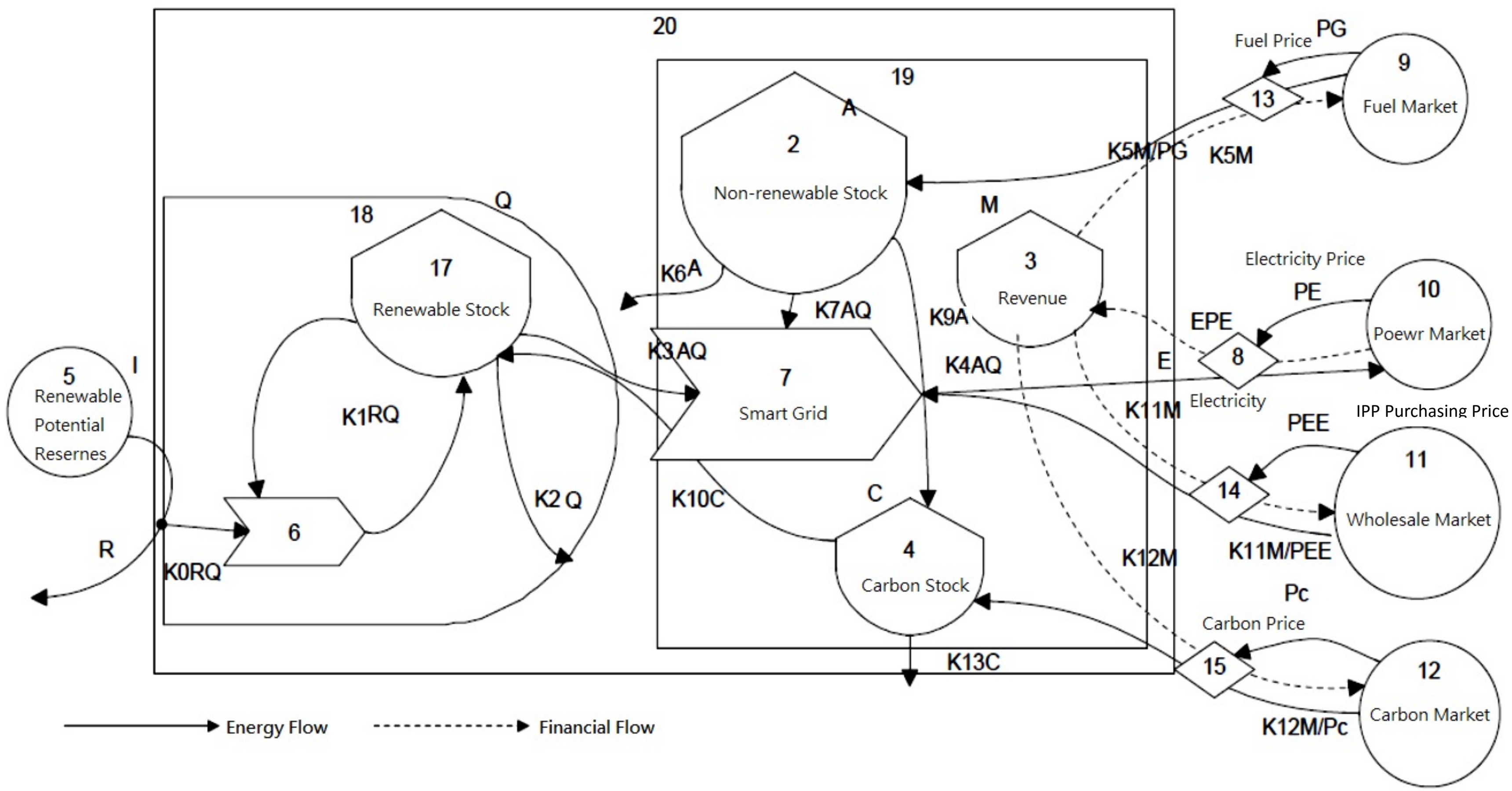


Figure 7. Power Resource Portfolio System Flowchart under Smart Grid (Simplified Model)

III. DEVELOPMENT OF SYSTEM DYNAMICS CASE SIMULATION FOR ADAPTIVE SMART GRID POWER SUPPLY AND DEMAND RESOURCES

A. Simplified modeling system diagram

Based on the energy balance principle (second law of non-equilibrium thermodynamics) under power supply and demand balance, the system diagram of developing a simplified power model is shown in Figure 7.

(1)The existent natural renewable energy will be controlled to get into the human system to become the stock, some of it back to the natural system;

(2)Renewable energy stocks (Q) and non-renewable energy stocks (A) consist of power (E) under the dynamic interaction. It needs to consider the economic and social demand for electricity supply under the consideration of planning and operating reliability reserve requirements, and it can be effectively managed by DSM;

(3)The sale of electricity to the user via the market trading with smart grid platform in order to gain profit for power value (M);

(4)Part of the revenue to fuel suppliers to purchase primary energy (become non-renewable energy stocks) and to buy power from IPP (Independent Power Producer), then powered with renewable energy portfolio to the user via feedback loop repeatedly;

(5)On the one hand, the fossil generators produce CO2 emissions to be carbon stock (carbon assets), on the other hand, it becomes to be carbon sinks via CCS asset management;

(6)The intermittent renewable energy preferentially supply electricity to households with household electric energy storage system, followed by energy storage system combined with the regional electricity supply (micro-grid), and finally in conjunction with smart grid systems to supply all users;

(7)Circulating type of renewable energy sources (biomass energy) from carbon assets become renewable energy stocks;

(8)The price considerations including exogenous and endogenous scenarios.

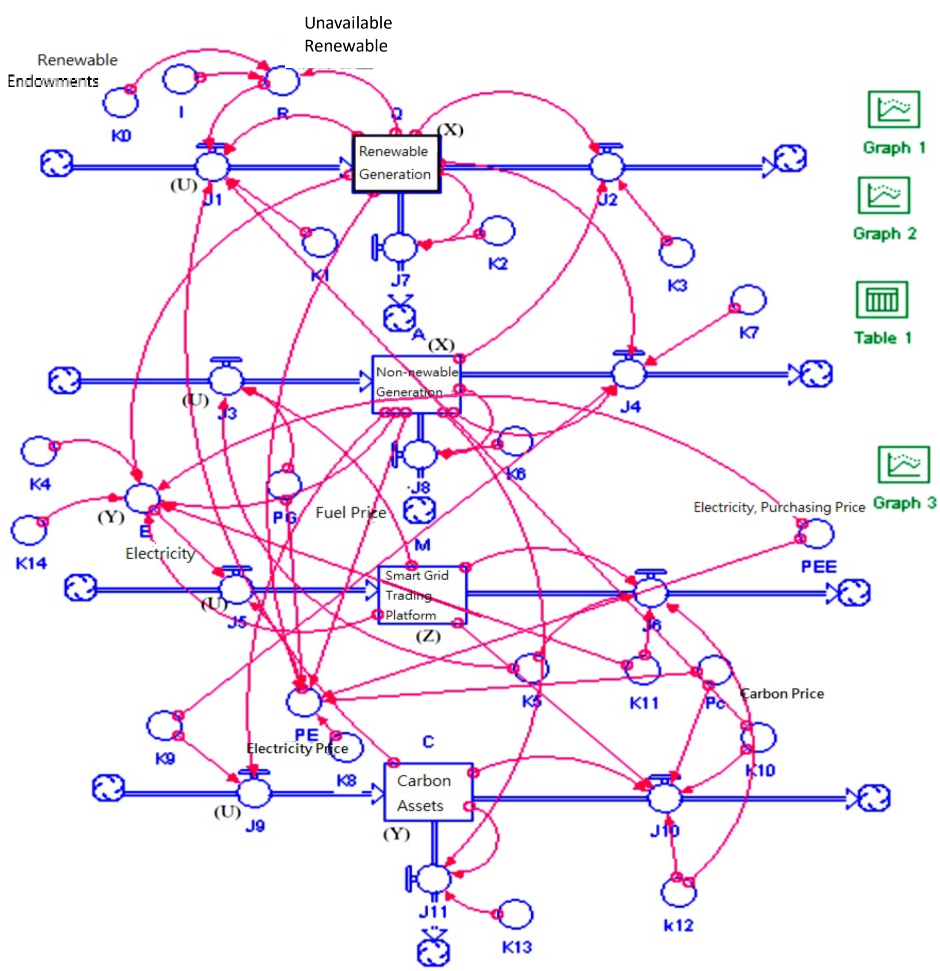


Figure 8. Power Resource Portfolio System Dynamics Diagram under Smart Grid (Simplified Model)

Note:1. (renewable energy, non-renewable energy resources) → (electricity value, carbon assets)

2. The adaptive control logic: X (state) → Y (measurement) → Z (performance) →U (control)

3. Energy resources portfolio mode: non-linear

B. Simplified Model System Dynamics Diagram

(1) According to the system diagram in Figure 7, the system equations were developed considering the energy balance of the contents, as follows:

I–R=K0*R*Q (14)
(the available renewable energy balance equation)

DQ=(K1*R*Q+K10*C)–(K2*Q+K3*A*Q) .. (15)
(the stock of renewable energy balance equation)

DA=K5*M/PG–(K8*A+K7*A*Q+K9*A) (16)
(the stock of non-renewable energy balance equation)

DM=PE*(K4*A*Q+K11*M/PEE)*K14–(K5*M+K11*M+K12*M) (17)
(profit balance equation)

DC=K9*A–(K10*C+K13*C+K12*M/Pc) (18)
(carbon balance equation)

E=(K4*A*Q+K11*M/PEE)* K14 (19)
(power supply equation)

PE=K8*A*Q *PG*PEE*Pc (20)
(power price equation)

(2) the construction of system dynamic simulation system diagram according to the above equation is shown in Figure 8. It is to carry out the simulation scenarios, including (a) the basic scenarios: By coupled modeling of renewable energy and non-renewable energy resources portfolio based on smart grid, the equilibrium & non-equilibrium scenario will be constructed considering 3E multi-objective model as a reference model of the coupled model [8] for adaptive dynamic simulation, covering 2015,2025,2035 national energy policy carbon structure comparing with 2013 current reference situation; (b) the simulation scenarios: In addition to be based on to the above different high-mid-low carbon structure, other considerations on demand, renewable energy endowments, fuel prices, power purchase price, the carbon price and the power price impact on the state variables (renewable energy stocks, the stock of non-renewable energy resources, carbon emissions), the observed variables (the available renewable energy, power supply, electricity price) and performance variables (profit) for sensitivity will be simulated.

IV. RESULTS OF SYSTEM DYNAMICS CASE SIMULATION FOR ADAPTIVE SMART GRID POWER SUPPLY AND DEMAND RESOURCES

A. Scenario Simulation

The simulation is divided into the situation context of exogenous & endogenous electricity price as shown in table 1 & table 2.

Firstly, the basic situational simulation are performed in 2013 (the current reference situation), 2015(short-term high-carbon policy objectives), 2025(mid-term middle-carbon policy objectives) and 2035 (long-term low-carbon policy objectives) respectively including equilibrium and non-equilibrium condition.

Secondly, the sensitivity simulation are considered, including (1)power demand (2)renewable endowments (3)fuel price (4)power purchasing price (5)carbon price (or carbon tax) and (6)power price respectively under two times & half times condition.

Finally, the simulation results of system behavior including evolution path & direction are shown in table1&2, the mode type with mode figure are shown in table 3.

From the results, not only we can see the evolution path & direction for state variable (X), measurement variable (Y) and performance variable (Z), but also we can see their mutual interaction, including (1)the complementary & substitutive relationship between renewable & non-renewable (2)the dependence relationship including: emission stock (C) depends on non-renewable (A); available-renewable (I-R) depends on renewable (Q); power supply (E) or power price (PE) depends on renewable (Q) & non-renewable (A); and profit (M) depends on power supply (E) & power price (PE) etc. (3) the impact of sensitivity for demand variable, resources variable, market variable and policy variable.

In addition, from table 3 we can see the characteristics of system behavior from its mode & figure, including (1) complexity (2) emergence (3) self-organization (4) dynamic (5) non-linear (6) stable (7) unstable (8) diversity (9) uncertain (10) chaos (11) path dependence (12) co-evolution etc.

TABLE 1 ENERGY RESOURCES PORTFOLIO SIMULATION RESULTS SUMMARY (FIXED PRICE)

Scenarios Simulation					Reaction Variables / (H,M,L) (Path, Direction) System Behavior	State Variable (X)			Measurement Variable (Y)			Performance Variable(Z)
						Renewable Stock (Q)	**Non-renewable Stock (A)**	**Emission Stock (C)**	**Available Renewable (I-R)**	**Power Supply (E)**	**Power Price (PE)**	**Profit (M)**
Control Variable (U)	Basic	Policy Situation (3E)	Power Portfolio J	Equilibrium	**Reference (2013,2013~2033)**	**(3,+)**	**(7, –)**	**(13, –)**	**(3,+)**	**(18,+)**	**Fix**	**(23, +)**
				Un-Equilibrium	**H-Carbon(2015,2013~2033)**	**(3,+)**	**(7, –)**	**(16, –)**	**(3,+)**	**(18,+)**	**Fix**	**(20, +)**
					M-Carbon(2025,2013~2033)	**(3,+)**	**(7, –)**	**(16, –)**	**(3,+)**	**(3,+)**	**Fix**	**(20,+)**
					L-Carbon(2035,2013~2033)	**(3,+)**	**(7, –)**	**(16, –)**	**(3,+)**	**(18,+)**	**Fix**	**(20,+)**
	Sensitivity	Demand Variable	Power Demand E		**2 times**	**(13, 18, 16) (–, –, +)**	**(12, 1, 1) (+, +, +)**	**(12, 1, 14) (+, +, +)**	**(13, 18, 16) (–, –, +)**	**(18, 16, 4) (+, +, +)**	**Fix**	**(3, 12, 2) (+, +, +)**
					0.5 times	**(12, 3, 3) (+, +, +)**	**(13, 13, 13) (–, –, –)**	**(16, 16, 16) (–, –, –)**	**(12, 3, 3) (+, +, +)**	**(8, 18, 18) (–, –, –)**	**Fix**	**(8, 8, 8) (–, –, –)**
		Resources Variable	Renewable Endowmentss I		**2 times**	**(3, 3, 3) (+, +, +)**	**(17, 17, 21) (+, –, –)**	**(13, 6, 5) (–, –, –)**	**(3, 3, 3) (+, +, +)**	**(22, 18, 22) (+, +, +)**	**Fix**	**(4, 4, 12) (+, +, +)**
					0.5 times	**(17, 17, 17) (–, –, –)**	**(16, 16, 16) (–, –, –)**	**(19, 4, 4) (+, +, +)**	**(17, 17, 17) (–, –, –)**	**(7, 8, 8) (–, –, –)**	**Fix**	**(8, 8, 8) (–, –, –)**
		Market Variable	Fuel Price PG		**2 times**	**(3, 3, 3) (+, +, +)**	**(7, 7, 7) (–, –, –)**	**(13, 6, 16) (–, –, –)**	**(3, 3, 3) (+, +, +)**	**(8, 18, 18) (–, –, –)**	**Fix**	**(13, 5, 15) (–, –, –)**
					0.5 times	**(13, 18, 16) (–, –, +)**	**(4, 9, 14) (+, +, +)**	**(12, 2, 2) (+, +, +)**	**(13, 18, 16) (–, –, +)**	**(18, 3, 4) (+, +, +)**	**Fix**	**(12, 12, 2) (+, +, +)**
			Power Purchasing Price PEE		**2 times**	**(12, 3, 3) (+, +, +)**	**(13, 13, 13) (–, –, –)**	**(5, 16, 16) (–, –, –)**	**(12, 3, 3) (+, +, +)**	**(13, 16, 18) (–, +, +)**	**Fix**	**(8, 15, 23) (–, –, –)**
					0.5 times	**(5, 16, 3) (–, +, +)**	**(2, 17, 17) (+, +, +)**	**(1, 22, 22) (+, +, +)**	**(5, 16, 3) (–, +, +)**	**(4, 4, 14) (+, +, +)**	**Fix**	**(4, 9, 9) (+, +, +)**
		Market (Policy) Variable	Carbon Price PC (Carbon Tax)		**2 times**	**(3, 3, 3) (+, +, +)**	**(17, 13, 13) (–, –, –)**	**(4, 4, 3) (+, +, +)**	**(3, 3, 3) (+, +, +)**	**(4, 3, 18) (+, +, +)**	**Fix**	**(2, 20, 20) (+, +, +)**
					0.5 times	**(13, 3, 3) (–, +, +)**	**(19, 13, 13) (+, –, –)**	**(8, 6, 6) (–, –, –)**	**(13, 3, 3) (–, +, +)**	**(5, 3, 18) (–, +, +)**	**Fix**	**(6, 12, 20) (–, +, +)**
			Power Price PE (Regulated)		**2 times**	**(13, 18, 16) (–, –, +)**	**(12, 1, 1) (+, +, +)**	**(12, 1, 14) (+, +, +)**	**(13, 18, 16) (–, –, +)**	**(18, 16, 4) (+, +, +)**	**Fix**	**(3, 12, 2) (+, +, +)**
					0.5 times	**(12, 3, 3) (+, +, +)**	**(13, 13, 13) (–, –, –)**	**(16, 16, 16) (–, –, –)**	**(12, 3, 3) (+, +, +)**	**(8, 18, 18) (–, –, –)**	**Fix**	**(8, 8, 8) (–, –, –)**

Note: 1. Q, A and I-R (billion kWh); 2. C (million ton);
3. M (million NTD); 4. E and PE (1 in equilibrium)

TABLE 2 ENERGY RESOURCES PORTFOLIO SIMULATION RESULTS SUMMARY (FLEXIBLE PRICE)

Scenarios Simulation					Reaction Variables / (H,M,L) (Path, Direction) System Behavior	State Variable (X)			Measurement Variable (Y)			Performance Variable (Z)
						Renewable Stock (Q)	**Non-renewable Stock (A)**	**Emission Stock (C)**	**Available Renewable (I–R)**	**Power Supply (E)**	**Power Price (PE)**	**Profit (M)**
Control Variable (U)	Basic	Policy Situation (3E)	Power Portfolio J	Equilibrium	**Reference(2013,2013~2033)**	(16, –)	(1, +)	(17, –)	(16, –)	(14,+)	(14, +)	(2, +)
				Un-equilibrium	**H-Carbon(2015,2013~2033)**	(3, +)	(13, –)	(16, –)	(3, +)	(16, –)	(16, –)	(15, –)
					M-Carbon(2025,2013~2033)	(3 ,+)	(13, –)	(16, –)	(3,+)	(16, –)	(16, –)	(15, –)
					L-Carbon(2035,2013~2033)	(3 ,+)	(13, –)	(16, –)	(3,+)	(16, –)	(16, –)	(15, –)
	Sensitivity	Demand Variable	Power Demand E		**2 times**	(13, 18, 16) (–, –, +)	(12, 1, 21) (+, +, +)	(12, 22, 22) (+, +, +)	(13, 18, 16) (–, –, +)	(18, 24, 14) (+, +, +)	(22, 24, 14) (+, +, +)	(18, 12, 2) (+, +, +)
					0.5 times	(12, 4, 3) (+, +, +)	(13, 13, 13) (–, –, –)	(16, 16, 16) (–, –, –)	(12, 4, 3) (+, +, +)	(13, 18, 18) (–, –, –)	(13, 18, 18) (–, –, –)	(8, 8, 8) (–, –, –)
		Resources Variable	Renewable Endowments I		**2 times**	(18, 18, 3) (–, –, +)	(19, 12, 17) (+, +, –)	(21, 21, 5) (+, +, –)	(18, 18, 3) (–, –, +)	(24, 24, 22) (+, +, +)	(24, 24, 22) (+, +, +)	(19, 19, 14) (+, +, +)
					0.5 times	(17, 17, 17) (–, –, –)	(18, 5, 5) (–, –, –)	(19, 16, 3) (+, +, +)	(17, 17, 17) (–, –, –)	(8, 8, 8) (–, –, –)	(8, 8, 8) (–, –, –)	(8, 8, 8) (–, –, –)
		Market Variable	Fuel Price PG		**2 times**	(14, 3, 3) (+, +, +)	(15, 8, 8) (–, –, –)	(13, 5, 16) (–, –, –)	(14, 3, 3) (+, +, +)	(15, 16, 18) (–, –, –)	(15, 18, 18) (–, –, –)	(16, 19, 15) (–, –, –)
					0.5 times	(7, 4, 4) (–, +, +)	(14, 16, 16) (+, –, –)	(12, 4, 3) (+, +, +)	(7, 4, 4) (–, +, +)	(4, 16, 16) (+, +, +)	(4, 16, 16) (+, +, +)	(17, 8, 15) (–, +, –)
			Power Purchasing Price PEE		**2 times**	(13, 16, 3) (–, –, +)	(12, 17, 21) (+, +, –)	(12, 22, 16) (+, +, +)	(13, 16, 3) (–, –, +)	(18, 14, 14) (+, +, +)	(22, 24, 14) (+, +, +)	(18, 2, 20) (+, +, +)
					0.5 times	(12, 4, 4) (+, +, +)	(13, 13, 13) (–, –, –)	(16, 16, 16) (–, –, –)	(12, 4, 4) (+, +, +)	(8, 18, 18) (–, –, –)	(13, 18, 18) (–, –, –)	(8, 8, 8) (–, –, –)
		Market (Policy) Variable	Carbon Price PC (Carbon Tax)		**2 times**	(13, 18, 16) (–, –, +)	(12, 1, 17) (+, +, +)	(12, 14, 14) (+, +, +)	(13, 18, 16) (–, –, +)	(18, 24, 14) (+, +, +)	(22, 24, 14) (+, +, +)	(18, 12, 2) (+, +, +)
					0.5 times	(12, 4, 3) (+, +, +)	(13, 13, 13) (–, –, –)	(8, 10, 5) (–, –, –)	(12, 4, 3) (+, +, +)	(13, 18, 18) (–, –, –)	(13, 18, 18) (–, –, –)	(8, 8, 8) (–, –, –)
			Power Price PE (Un-regulated)		**2 times**	(13, 18, 16) (–, –, +)	(12, 1, 21) (+, +, +)	(12, 22, 22) (+, +, +)	(13, 18, 16) (–, –, +)	(18, 24, 14) (+, +, +)	(22, 24, 14) (+, +, +)	(18, 12, 2) (+, +, +)
					0.5 times	(12, 4, 3) (+, +, +)	(13, 13, 13) (–, –, –)	(16, 16, 16) (–, –, –)	(12, 4, 3) (+, +, +)	(13, 18, 18) (–, –, –)	(13, 18, 18) (–, –, –)	(8, 8, 8) (–, –, –)

Note: see Table 1 for units of each variables.

TABLE 3 EVOLUTION PATH OF ENERGY RESOURCES PORTFOLIO SUMMARY

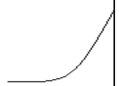
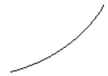
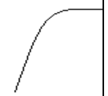
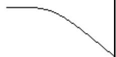
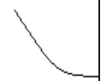
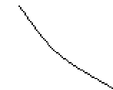
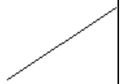
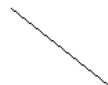
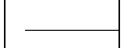
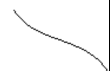
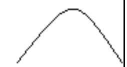
Mode Type	Mode Fig	Mode Type	Mode Fig	Mode Type	Mode Fig	Mode Type	Mode Fig
1. nonlinear positive feedback increase from equilibrium (emergent growth away from the target)		2. nonlinear positive feedback increase (emergent growth)		3.nonlinear negative feedback increase balance (goal-driven growth)		4.nonlinear negative feedback increase (regulated growth)	
5. nonlinear positive feedback decrease far from equilibrium (emergent attenuation away from the target)		6 nonlinear positive feedback decrease (emergent attenuation)		7 nonlinear negative feedback decrease balance (goal-driven attenuation)		8.nonlinear negative feedback decrease (regulating attenuation)	
9 linear increase		10 linear decrease		11. fixed balance		12. nonlinear positive feedback then negative feedback increase from one equilibrium to another (S curve growth)	
13. nonlinear positive feedback then negative feedback decrease from one equilibrium to another (anti-S curve attenuation)		14. nonlinear negative feedback then positive feedback increase (inverted S curve growth)		15.nonlinear negative feedback then positive feedback decrease (inverted anti-S curve attenuation)		16.nonlinear negative feedback increase then positive feedback decrease (parabola fluctuation)	
17.nonlinear negative feedback decrease then positive feedback increase (bath fluctuation)		18.nonlinear negative feedback increase then negative feedback decrease (excessive regulating growth then attenuation)		19. nonlinear positive feedback increase from equilibrium then positive feedback decrease (excessive emergent growth then decay)		20.nonlinear negative feedback decrease then negative feedback increase (excessive regulating attenuation then growth)	
21. nonlinear positive feedback decrease from equilibrium then positive feedback increase (excessive emergent attenuation then growth)		22.nonlinear negative feedback increase then positive feedback decrease and positive feedback increase (N-type oscillations)		23.nonlinear negative feedback decrease then negative feedback increase and positive feedback decrease (anti N-type oscillations)		24. chaos (bifurcation)	

TABLE 4 POWER RESOURCES MIX SIMULATION RESULTS SUMMARY (FIXED PRICE) (QUANTITATIVE)

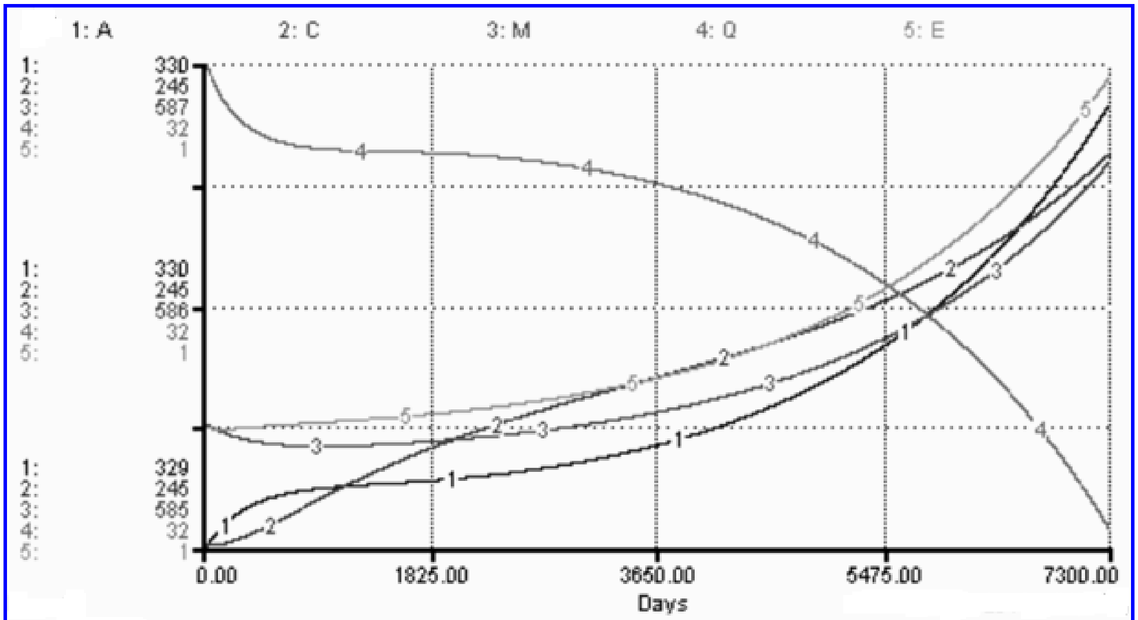
Scenarios Simulation \ System Behavior (Value,Type)			State Variable (X)			Measurement Variable (Y)			Performance Variable(Z)
			Renewable Stock (Q)	Non-renewable Stock (A)	Emission Stock (C)	Available Renewable (I-R)	Power Supply (E)	Power Price (PE)	Value (M) Profit/Revenue
Scenario A Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2013)	(32,31.993,31.994) C(20, –)	(329,329.103,329.098) C(18, +)	(245,245.13,245.15) B(12, +)	(424,423.95,423.96) C(20, –)	(0.99999,1.000007, 1.000009) D(23,+)	Fix	(585,584.889,584.8892) A(7, –)
	Non-equilibrium (3E Coupling)	H-Carbon (2015)	(32, 93, 89) A(3,+)	(329,298,331) D(22, +)	(245,201.7,195.7) B(13, –)	(239.5,452.4,443.9) A(3,+)	(0.415,0.79,0.844) A(4,+)	Fix	(585,669,719) C(20, +)
		M-Carbon (2025)	(32,182,171) A(3,+)	(329,217,262) D(22, –)	(245,204.9,179) C(18, –)	(199.4,488.4,475.4) A(3,+)	(0.242,0.585,0.666) A(4,+)	Fix	(585,745,857) C(20, +)
		L-Carbon (2035)	(32,228,221) A(3,+)	(329,173,197) D(22, –)	(245,219.6,179.8) C(18, –)	(140.6,497,490.8) A(3,+)	(0.163,0.394,0.438) D(22, +)	Fix	(585,737,825) C(20, +)
Scenario B Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2015)	(81,81.583,81.581) A(3,+)	(429,427.39,427.21) B(13, –)	(250,248.1,247.6) B(13, –)	(423.2,424.74,424.73) A(3,+)	(0.999,1.0011,1.0007) C(18, +)	Fix	(865,865.37,864.96) D(23, –)
	Non-equilibrium (3E Coupling)	H-Carbon (2013)	(81, 29, 31) C(20, –)	(429,406,361) D(23, –)	(250,306,279.5) D(23, +)	(607.9,401,411) C(20, –)	(2.754,1.112,1.055) A(7, –)	Fix	(865,660,621) C(18, –)
		M-Carbon (2025)	(81, 161, 153) A(3,+)	(429,326,366) B(17, –)	(250,239,233) C(18, –)	(319,462,451) A(3,+)	(0.561,0.782,0.838) A(4,+)	Fix	(865,1019,1102) C(20, +)
		L-Carbon (2035)	(81,211,205) A(3,+)	(429,261,290) B(17, –)	(250,244,220) C(18, –)	(283.8,481.5, 474.8) A(3,+)	(0.38,0.554,0.599) D(22, +)	Fix	(865,1051,1145) C(20, +)
Scenario C Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2025)	(134,133.73,133.56) A(8, –)	(494, 495.42,496.64) A(4,+)	(313,313.2,313.8) A(1,+)	(423.92,423.5,423.23) A(8, –)	(1.002,1.004,1.005) C(20, +)	Fix	(865,1351,1353) A(4,+)
	Non-equilibrium (3E Coupling)	H-Carbon (2013)	(134, 26, 30) C(20, –)	(494,474,387) D(23, –)	(313,384.1,309.9) D(23, –)	(684.5,383.7,408.3) C(20, –)	(5.093,1.202,1.097) A(7, –)	Fix	(1348,718,649) C(18, –)
		M-Carbon (2015)	(134, 69, 75) C(20, –)	(494,605,528) D(23, +)	(313,327.8,307.1) D(23, –)	(527.8,389.6,406) C(20, –)	(1.798,1.212,1.138) A(8, –)	Fix	(1348,1072,997) B(13, –)
		L-Carbon (2035)	(134,189,184) A(3,+)	(494,401,429) B(17, –)	(313,304.4,293) C(18, –)	(385.2,457.5, 451.8) A(3,+)	(0.678,0.767,0.8) C(18, +)	Fix	(1348,1486,1559 A(4,+)
Scenario D Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2035)	(161,160.999,160.998) D(24, –)	(605,604.942,604.930) B(15, –)	(392,391.83,391.76) A(7, –)	(423.9597,423.9591, 423.9571) D(24, –)	(0.999442,0.999371, 0.999342) A(7, –)	Fix	(1994,1993.987,1993.93 B(16, –)
	Non-equilibrium (3E Coupling)	H-Carbon (2013)	(161, 25, 29) C(20, –)	(605,523,404) D(23, –)	(392,457.1,331.9) D(23, –)	(707.4,373.8,404.1) C(20, –)	(7.5,1.264,1.124) A(7, –)	Fix	(1994,754,667) C(18, –)
		M-Carbon (2015)	(161,58,70) C(20, –)	(605,801,605.01) C(18, +)	(392,422.6,356.1) D(23, –)	(563.5,354.2,392.5) C(20, –)	(2.65,1.36,1.23) A(7, –)	Fix	(1994,1225,1087) B(13, –)
		L-Carbon (2025)	(161,106,119) C(20, +)	(605,720,617) C(18, +)	(392,417.6,400.8) D(23, +)	(462.7,375,399.2) C(20, +)	(1.477,1.18,1.124) A(8, –)	Fix	(1994,1653,1543) B(13, –)

Note: see Table 1 for units of each variables.

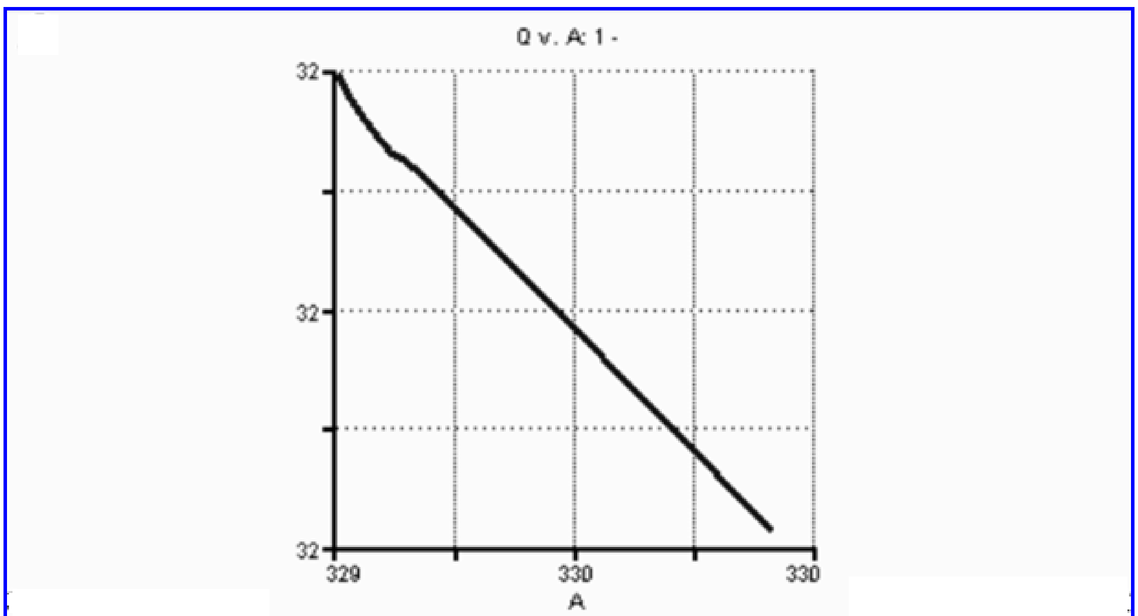
TABLE 5 POWER RESOURCES MIX SIMULATION RESULTS SUMMARY (FLEXIBLE PRICE) (QUUANTITATIVE)

System Behavior (Value,Type) / Scenarios Simulation			State Variable (X)			Measurement Variable (Y)			Performance Variable(Z)
			Renewable Stock (Q)	Non-renewable Stock (A)	Emission Stock (C)	Available Renewable (I-R)	Power Supply (E)	Power Price (PE)	Value (M) Profit/Revenue
Scenario A Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2013)	(32,31.99,31.95) B(15, –)	(329,329.2,329.9) B(14, +)	(245,245.14,245.33) B(14, +)	(424,423.92,423.68) B(15, –)	(0.999,1.0002,1.0014) A(1, +)	(0.999,1.0002,1.0012 A(1, +)	(585,585.06,586) A(1, +)
	Non-equilibrium (3E Coupling)	H-Carbon (2015)	(32,122,128) A(3,+)	(329,50,1) B(13, –)	(245, 174.4, 89.2) B(16, –)	(239.5, 509.3, 518.6) A(3,+)	(0.415,0.157,0.003) C(18, –)	(0.303,0.176,0.004 C(18, –)	(585,98,2 B(15, –)
		M-Carbon (2025)	(32,224,234) A(3,+)	(329,42,3.5) B(13, –)	(245, 191.7,111.9) B(16, –)	(163.4,530.2, 539) A(3,+)	(0.242,0.129,0.011) C(18, –)	(0.159,0.143,0.012 C(18, –)	(585, 131, 11 B(15, –)
		L-Carbon (2035)	(32,253,262) A(3,+)	(329,49,9.2) B(13, –)	(245, 213.6, 141) B(16, –)	(140.6, 518.5, 525) A(3,+)	(0.163,0.117,0.022) C(18, –)	(0.108,0.129,0.025 C(18, –)	(585, 182, 34 B(15, –)
Scenario B Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2015)	(81,80.4,75) A(5, –)	(429, 442, 518) A(1, +)	(250,249.6, 261.1) A(17, +)	(423.2, 421.8, 406.1) A(5, –)	(0.999,1.024,1.134) A(1, +)	(1.001,1.023,1.114 A(1, +)	(865,893,1027) A(1, +)
	Non-equilibrium (3E Coupling)	H-Carbon (2013)	(81,17,16) A(7, －)	(429, 761, 848) D(22, +)	(250, 410.8,458.8) C(20, +)	(607.9, 296.2, 276.8) A(7, –)	(2.754,1.370,1.395) A(7, –)	(3.300,1.242,1.249 A(7, –)	(865,976,1016) D(22, +)
		M-Carbon (2025)	(81,201,230) A(3,+)	(429,124,16) B(13, –)	(250,220.4, 139.7) B(16, –)	(319.4, 508.5, 536.1) A(3,+)	(0.561, 0.350,0.050) C(18, –)	(0.525,0.378,0.055 C(18, –)	(865, 380, 49) B(15, –)
		L-Carbon (2035)	(81,242,259) A(3,+)	(429,99,22) B(13, –)	(250,234.2, 161.7) B(16, –)	(283.8, 508.8, 523) A(3,+)	(0.380, 0.227,0.052) B(18, –)	(0.357,0.246,0.058 B(18, –)	(865, 365, 80) B(15, –)
Scenario C Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2025)	(134,133.5,132.4) A(5, –)	(494,497,505) A(1, +)	(313,313.3, 315.2) A(1, +)	(423.9, 423.2, 421.3) A(5, –)	(1.002,1.006,1.016) A(1, +)	(1.001,1.003,1.012 A(1, +)	(1348,1356,1374) A(1, +)
	Non-equilibrium (3E Coupling)	H-Carbon (2013)	(134,16,15) A(7, –)	(494,841,875) D(22, +)	(313,478,477.6) D(23, +)	(684.5, 282.2, 271.7) A(7, －)	(5.093,1.435,1.406) A(7, －)	(6.287,1.275,1.254 A(7, －)	(1348,1057,1030) D(22, +)
		M-Carbon (2015)	(134,33,29) A(7, –)	(494, 1426, 1654) A(3,+)	(313,459.7, 551.1) C(20, +)	(527.8, 245.8, 222.6) A(7, －)	(1.798,1.592,1.637) C(20, –)	(1.906,1.363,1.378 A(7, －)	(1348,1846,1945) A(3,+)
		L-Carbon (2035)	(134,214,246) A (3 , +)	(494,238,82) A(8 ,–)	(313, 294, 223.8) B(16, –)	(385.2, 484.3, 512.3) A(3,+)	(0.678, 0.494,0.189) B(16, –)	(0.679,0.523,0.205 B(16, –)	(1348,854, 301) B(15, –)
Scenario D Value:(2013, 2023,2033) Type:(Path,Direction)	Equilibrium	Reference (2035)	(161,161.1,161.4) A(1, +)	(605, 604, 601.8) A(5, –)	(392,391.8,391.2) A(5, –)	(424, 424.1, 424.5) A(1,+)	(0.999, 0.998,0.996) A(5, –)	(0.999,0.998,0.996 A(5, –)	(1994,1991,1985) A(5, –)
	Non-equilibrium (3E Coupling)	H-Carbon (2013)	(161,15.4,15) A(7, －)	(605,893,892.5) D(22, +)	(392,536.4, 490.2) D(23, +)	(707.4, 275.6, 268.6) A(7, －)	(7.499,1.482,1.413) C(20, －)	(9.252,1.307,1.257 C(20, －)	(1994,1106,1038) D(22, –)
		M-Carbon (2015)	(161,30,28) A(7, －)	(605, 1609, 1712) D(22, +)	(392,570.9, 567.5) D(22, +)	(563.5, 229.5, 216.3) A(7, －)	(2.650,1.611,1.635) D(24, –)	(2.805,1.398,1.373 D(24, –)	(1994,1829,1952) D(22, –)
		L-Carbon (2025)	(161,70,68) A(7, －)	(605, 1156, 1225) A(3,+)	(392,486.3, 566.6) C(20, +)	(462.7, 290.3, 284.4) A(7, －)	(1.477, 1.355,1.395) D(23, –)	(1.473,1.220,1.253 D(23, –)	(1994,2242,2316) D(22, +)

Note: see Table 1 for units of each variables.



Equilibrium (2013, Structure)

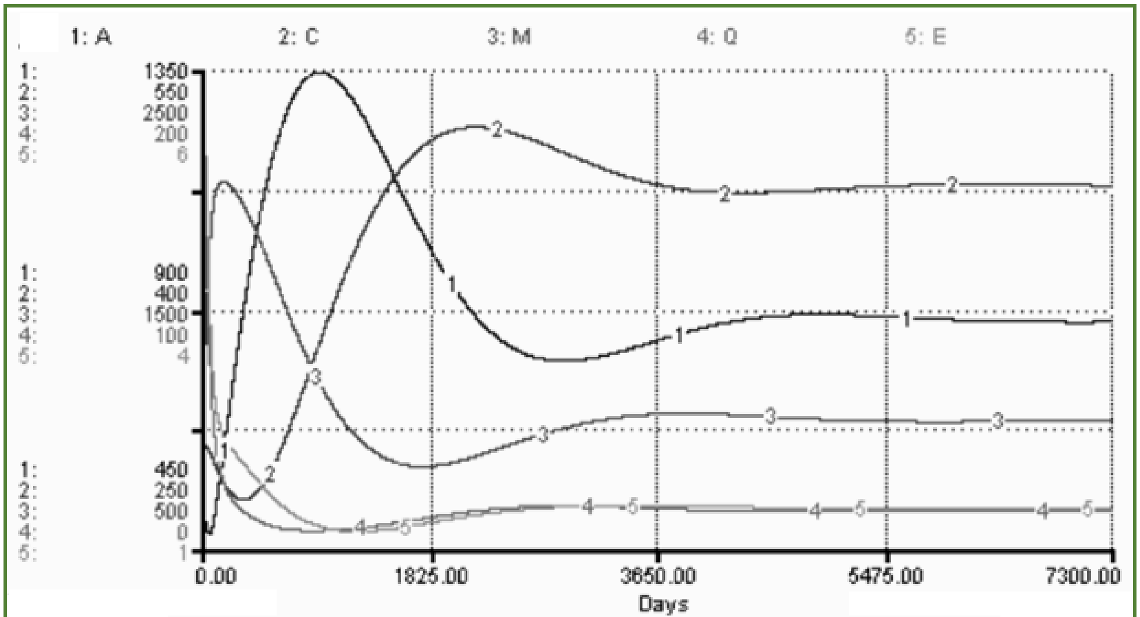


LINEAR (EQUILIBRIUM)

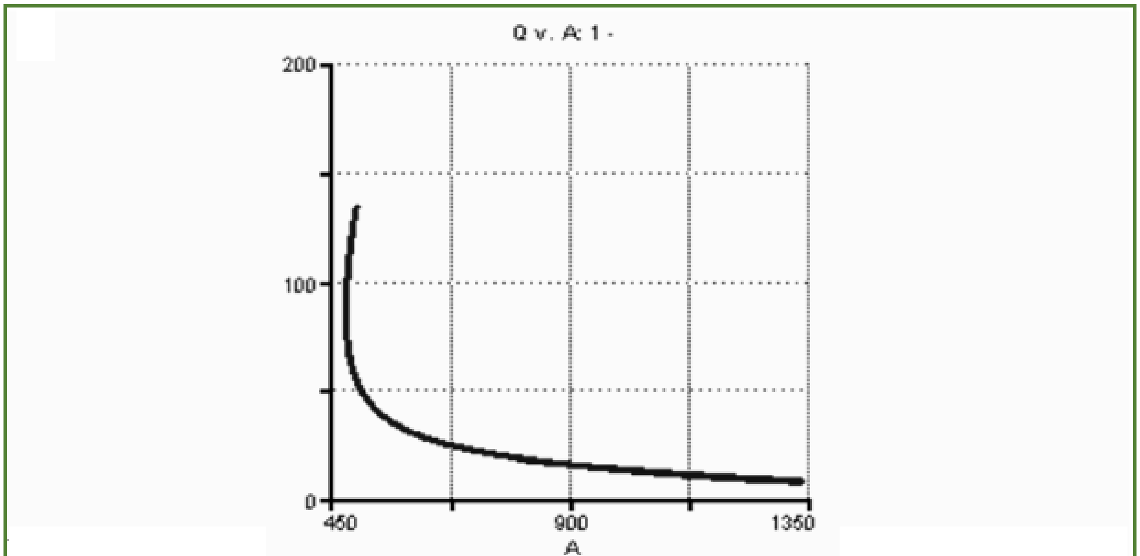
Figure 9. 2013 Current Power Portfolio Structure under Equilibrium

Note:

1. A (Non-renewable, billion kWh)
2. C (Carbon Emission, million ton)
3. M (Profit, billion NTD)
4. Q (Renewable, billion kWh)
5. E (Electricity, 1 in equilibrium)

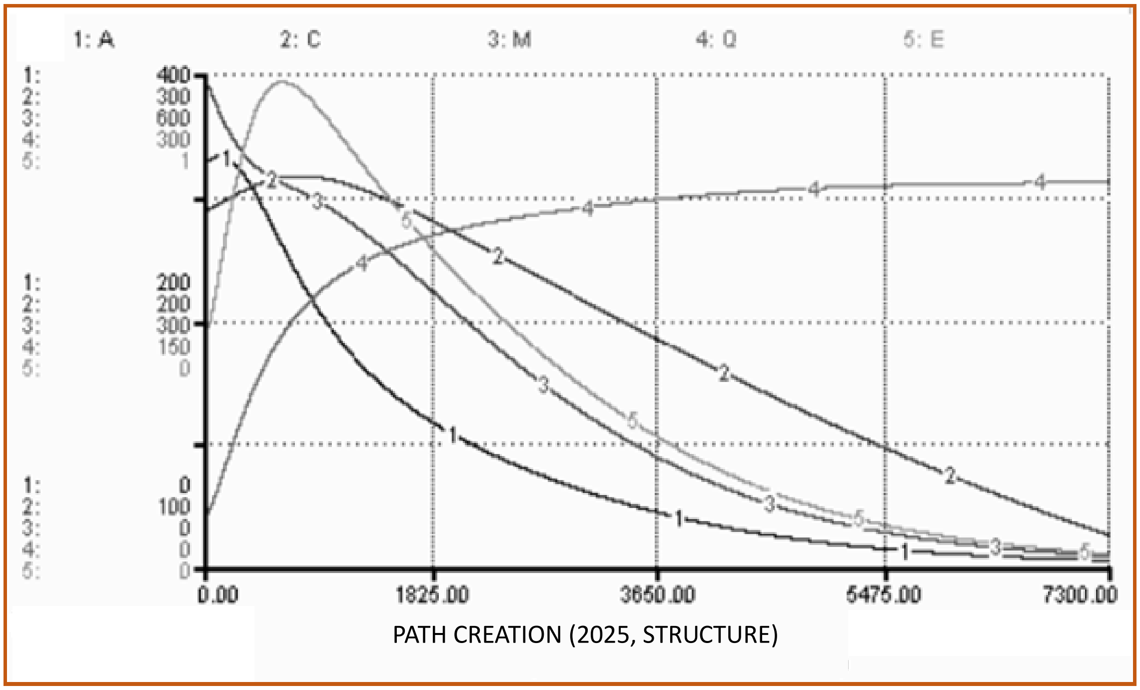


PATH DEPENDENCE (LOCK-IN 2013 STRUCTURE)



NONLINEAR(NON-EQUILIBRIUM)

Figure 10. 2013 Current Power Portfolio Structure under Non-equilibrium (Path Dependence)



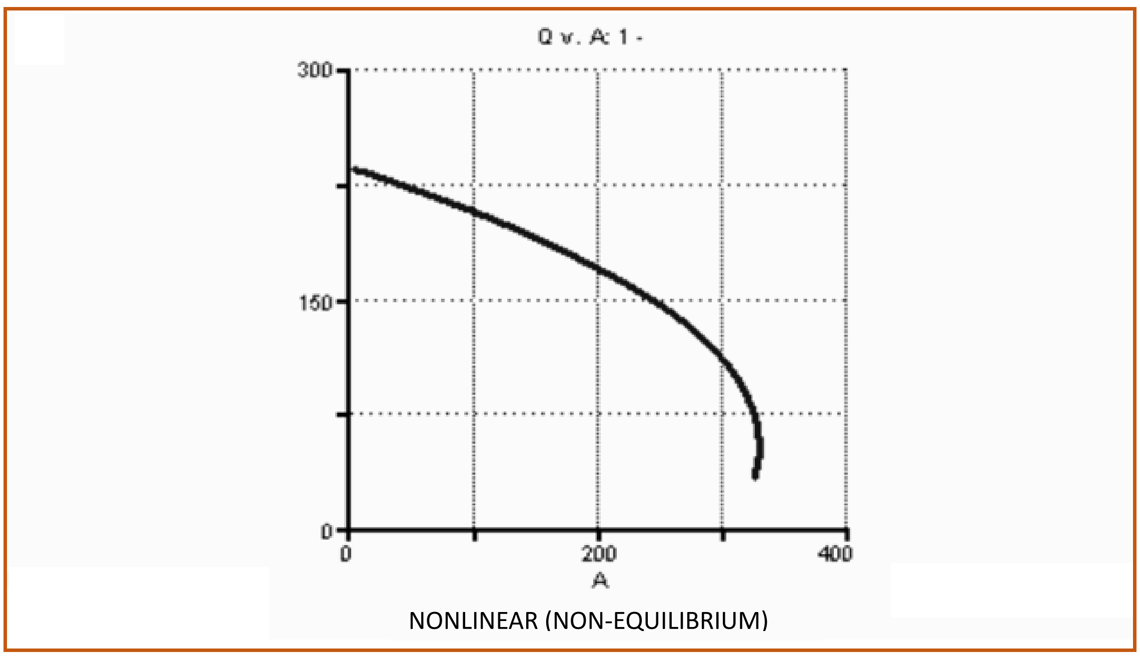
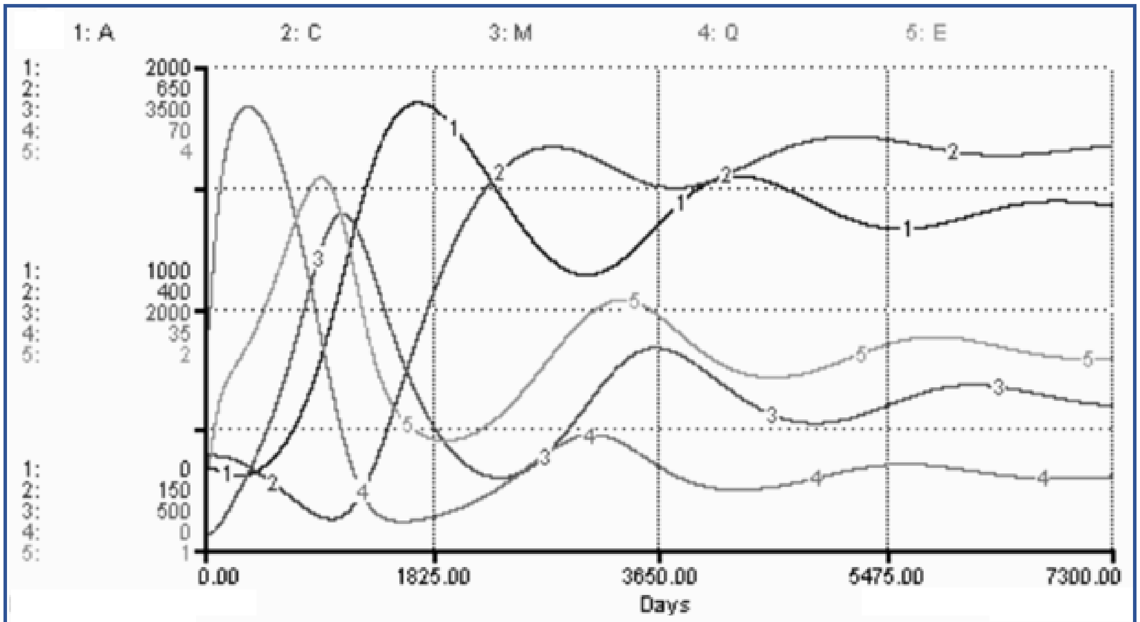
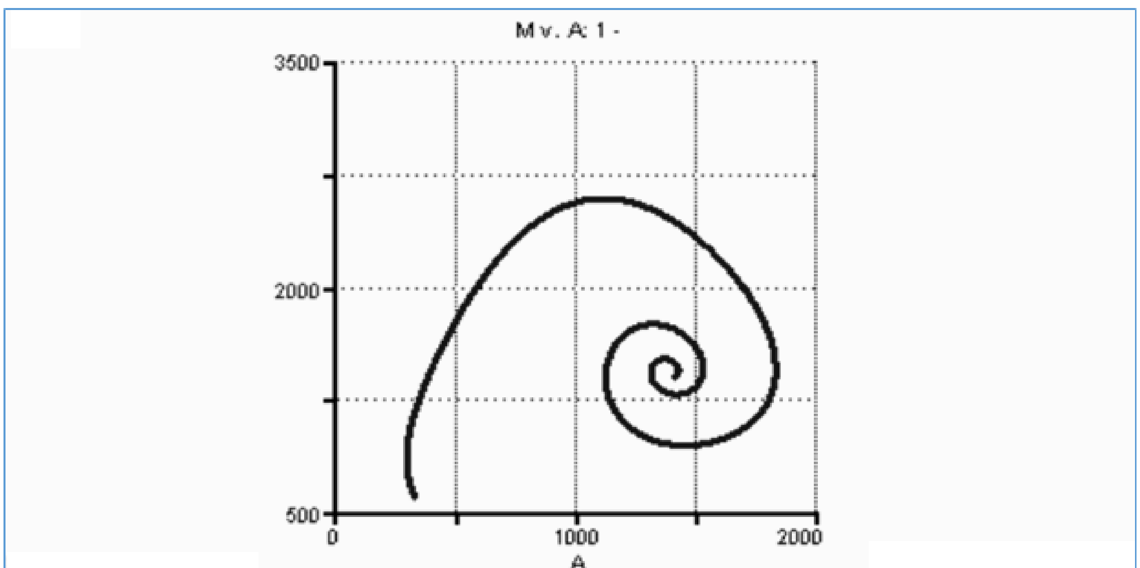


Figure 11. 2025 Future Power Portfolio Structure under Disequilibrium (Path Creation)



CHAOS (DAMPED OSCILATION)



CHAOS (POINT EXTRACTOR)

Figure 12. Sensibility Simulation for Power Portfolio Structure under Disequilibrium

Note: Point Extractor → Periodic Extractor → Quasi-Periodic Extractor → Strange Extractor (Chaos)

B. Simulation Results and Overall Implications

1) Fundamental Implications

a. Behavior Analysis

i) Basic type: It consists of the form of negative (balancing) feedback towards the energy policy goals (increase or decrease) and positive (reinforcing) feedback by the emergent behavior of self-organized energy resources portfolio (increase or decrease), including: (1) nonlinear positive feedback increase from equilibrium (emergent growth away from the target), (2) nonlinear positive feedback increase (emergent growth), (3) nonlinear negative feedback increase balance (goal-driven growth), (4) nonlinear negative feedback increase (regulated growth), (5) nonlinear positive feedback decrease far from equilibrium (emergent attenuation away from the target), (6) nonlinear positive feedback decrease (emergent attenuation), (7) nonlinear negative feedback decrease balance (goal-driven attenuation), (8) nonlinear negative feedback decrease (regulating attenuation), (9) linear increase, (10) linear decrease, (11) fixed balance. It shows to be the nonlinear negative feedback decrease or increase behavior for non-renewable and renewable energy towards the energy policy objectives coupling it with 3E model. In addition, the non-linear positive feedback emergent decrease or increase characteristics are driven by their mutual interaction and combination. It implies that we need an adaptive smart grid energy resources portfolio structure under adaptive policies in the future.

ii) Combination type: It is the composite of the form of the basic type, including: (1) nonlinear positive feedback then negative feedback increase from one equilibrium to another (S curve growth), (2) nonlinear positive feedback then negative feedback decrease from one equilibrium to another (anti-S curve attenuation), (3) nonlinear negative feedback then positive feedback increase (inverted S curve growth), (4) nonlinear negative feedback then positive feedback decrease (inverted anti-S curve attenuation), (5) nonlinear negative feedback increase then positive feedback decrease (parabola fluctuation), (6) nonlinear negative feedback decrease then positive feedback increase (bath fluctuation). It shows to be the positive and negative feedback combination of the smart grid energy resources portfolio under the complex interaction effects and the emergence of complex adaptive behavior. It implies that the adaptive behavior enhancement mechanism of coordination are required for smart grid energy resources portfolio in the future.

iii) Uncertain type: Due to the time lag effect resulting from the asynchronous effect between information transfer and control functions, such that the formation of a rebound instability or overshooting oscillation behavior induce the complex uncertain and stochastic scenarios. including: (1) nonlinear negative feedback increase then negative feedback decrease (excessive regulating growth then attenuation), (2) nonlinear positive feedback increase from equilibrium then positive feedback decrease (excessive emergent growth then decay), (3) nonlinear negative feedback decrease then negative feedback increase (excessive regulating attenuation then rebound growth), (4) nonlinear positive feedback decrease from equilibrium then positive feedback increase (excessive emergent attenuation then growth). It shows that the composite of the positive and negative feedback effects could cause overshooting or unstable behavioral characteristics. Its implications for the smart grid energy resources portfolio are the combination of interactive feedback could induce non-adaptive disordered behavior, such that it needs to be resilient to the disorder adaptively. We also highlight the requirements to match the smart grid infrastructure in order to facilitate the coordination and control of renewable and non-renewable energy.

iv) Chaos type: It is formed due to the internal stochastics derived from complex interactive feedback, including: (1) nonlinear negative feedback increase then positive feedback decrease and positive feedback increase (N-type periodic oscillations), (2) nonlinear negative feedback decrease then negative feedback increase and positive feedback decrease (anti N-type periodic oscillations),(3) chaos (bifurcation, non-periodic variation). It shows that the time lag positive and negative feedback effects will result in the continued instability in the system through the oscillatory or chaos behavior. Its implications are the adaptive behavior pursuit of smart grid energy resources portfolio under power system development, as well as the future adaptive characteristics of dynamic pricing under the non-regulated market.

b. Structure Analysis

The simulation results show: (1) the direction and path of development for the state variable (X), the observed variable (Y) and the performance variables (Z), (2) the alternative and complementary relationship between the renewable energy (Q) & the non-renewable energy (A) resources, (3) the dependency of carbon emission (C) on the non-renewable energy (A); the dependency of the system renewable energy (Q) on the natural available renewable energy resources (I-R); the dependency of the electricity (E) & the price (PE) on the renewable energy (Q) & the non-renewable energy (A), (4) the dependency of revenue (M) on the electricity (E) & the price (PE), (5) the sensitivity of controllable variables (U), including the electricity demand, resource endowments, market prices and policies.

c. Path Dependence Analysis (Fig 9~12)

i) Equilibrium (reference point)

Based on the 2013 energy resources portfolio structure with the initial value of 2013, the simulation results for the equilibrium under the evolutionary dynamic scenario show that: (a) the time series diagram shows the near-equilibrium situation (b) the phase diagram shows the linear relationship between the renewable energy and non-renewable energy, as shown in Figure 9.

ii) Lock-in Effect

Based on the 2013 energy resources portfolio structure with the initial value of 2025 (mid-term low-carbon target), the simulation results for the non-equilibrium under the evolutionary dynamic scenario show that: (a) the renewable energy towards decreasing by the non-linear negative feedback increase following non-linear negative feedback decrease (b) the non-renewable energy towards increasing by the non-linear negative feedback incremental increase oscillation following negative feedback increase (c) the electricity towards decreasing by the non-linear negative incremental increase oscillation following the negative feedback incremental decrease (d) the revenue towards increasing by the non-linear negative incremental increase oscillation following the negative feedback increase (e) the carbon emissions towards increasing by the non-linear feedback incremental increase then negative feedback decrease oscillation following the negative feedback incremental decrease (f) Implication: Under the high-carbon structure path dependence, any measures towards the low-carbon efforts (initial value) would result in lock-in effect limitation and instability phenomenon including the coevolution for the decrease of renewable, the increase of non-renewable and the increase of carbon emissions as shown in Figure 10. It should be applied to adaptive variable structure control.

iii) Path Creation

Based on the 2025 energy resources portfolio structure with the initial value of 2013, the simulation results for the non-equilibrium under the evolutionary dynamic scenario show that: (a) the renewable energy towards increasing by the non-linear negative feedback increase (goal driven type) (b) the non-renewable towards decreasing by the anti-S curve path (c) the electricity towards decreasing unstably by the negative feedback incremental decrease following the negative feedback increase (d) the revenue towards decreasing by the inverted anti-S curve path (e) the carbon emissions towards decreasing by the non-linear negative feedback decrease following the negative feedback increase (f) Implication: Under the mid–term low carbon structure path dependence, any measures towards the low carbon efforts would result in nonlinear path creation effect including the coevolution for the increase of renewable, the decrease of non-renewable, the decrease of carbon emissions and low marginal cost as shown in Figure 11. It should be applied to adaptive innovation & coordination control.

iv) Chaos effect

Based on the 2013 energy resources portfolio structure with the half flow parameter of the available renewable energy, the simulation results for the non-equilibrium under the evolutionary dynamic sceneries show that: (a) the times series diagram shows the oscillation behavior including renewable, non-renewable, electricity, revenue and carbon emissions (b) the phase diagram shows the attractor behavior including the point attractor, periodic attractor, qusi-periodic attractor and chaos attractor (c) Implication: The existence of uncertainty for the energy resources portfolio especially the intermittent renewable energy would result in the formation of the order out of disorder. It should be applied to the adaptive chaos control.

d. Quantitative Analysis

i) Event simulation (scenario description)

Considering (a) a combination structure of energy resources portfolio in 2013 (the current situation), (b) a combination structure of energy resources portfolio in 2015 (near-term low-carbon structure policy), (c) a combination structure of energy resources portfolio in 2025 (mid-term low-carbon structures policy), (d) a combination structure of energy resources portfolio in 2035 (long-term low-carbon structure policy), simultaneously it takes into account of 2013, 2015, 2025, 2035 equilibrium values as its initial value respectively. Accordingly, the A ~ D simulation scenarios are shown in Table 4 and Table 5.

ii) Simulation Results

(a) As the combination structure of energy resources portfolio in 2015 with the initial value in 2013, the simulation results show that: in 2033, three times the increase of renewable energy (electricity price exogenous) / four times (electricity price endogenous).

(b) As the combination structure of energy resources portfolio in 2025 with the initial value in 2013, the simulation results show that: in 2033, six times the increase of renewable energy (electricity price exogenous) / seven times (electricity price endogenous).

(c) As the combination structure of energy resources portfolio in 2035 with the initial value in 2013, the simulation results show that: in 2033, seven times the increase of renewable energy (electricity price exogenous) / eight times (electricity price exogenous).

(d) The non-renewable energy resources will be towards a decreasing trend under the electricity price exogenous circumstances, while in the case of the endogenous price in 2033, it would be close to reach a low-carbon renewable energy dominated situation.

(e) Under the combination structure of low-carbon energy resources portfolio (the policy objectives combined with the smart grid), in 2033, the renewable energy will become a major energy rather than the non-renewable energy has become to be the auxiliary energy.

(f) When the proportion of renewable energy is much higher than the proportion of non-renewable energy resources, the trend toward the low (zero) marginal costs and low marginal revenue indicates the possibility of realizing “share economy” under the energy resources portfolio of smart grid in the future.

2) Extended Implications

a) Under the simulation design of energy and demand-supply equilibriums, the adaptive power supply of adaptive portfolio of renewable and nonrenewable energy indicates that adaptive power demand under adaptive demand-side management and the adaptive power supply under adaptive operating reserve (or reserve margin). It develops in the direction toward a comprehensive, dynamic, adaptive combination of supply-side, demand-side and storage resources.

b) From adaptive renewable energy development potential, reflecting the goal-driven growth & the S curve increasing trend of renewables and the goal-driven attenuation & the anti-S curve decreasing trend of non-renewables.

c) From adaptive power price, fuel price, power purchase price, carbon price and its adaptive price-volume relationship, the adaptive power price dynamic characteristic under un-regulated market is reflected.

d) From adaptive power supply, power price and the balance between revenue and cost, reflecting the flexible characteristics of adaptive profit on state feedback, output feedback & performance feedback.

e) In terms of methodology, the modeling of this study initially verify that under smart grid (a) the practical application combined with feedforward (3E coupled model) and the reference model of adaptive feedback control system theory based on dynamic simulation of path dependence (b) the adaptive energy resources portfolio from negative feedback dynamic relationship, revealing the future electricity system towards characteristics of basic type, combination type, uncertain type and chaos type composites under their complementary and substitutive relationships. It implies its evolutionary path from the control economy, the market economy to the collaborative economy and to be the adaptive economy (c) the collaborative energy resources portfolio from the synergistic combination of price, quantity and quality reveals the adaptive asset management business strategy of internet of things towards the integration of policies, market, technology and business model. It also shows the future trend of adaptive management of electricity on the combination of the state variables, measured variables, performance variables and control variables. In addition, it highlights the importance of the adaptive requirements on non-adaptive policies and enhancement of robust smart grid infrastructure.

C. Power Industry Operational Management Implications

To sum up the works above, we go through the concept design, simplified simulation model and finally get some empirical results. We investigate the mutual relationships and adaptive system behavior by observing the state variables (renewable energy stocks, the stock of non-renewable energy resources, carbon stocks), measured variables (available renewable Energy, power supply, electricity price), performance variables (profit) and the reference target (3E coupled model under the National Energy Policy) and other control variables (electricity demand, renewable endowments, fuel price, IPP purchase price, the carbon price (tax), electricity price) under simulation. It shows that the power industry in the face of internal and external environment, including economy, energy, climate change technology, policy, business model and many other uncertainties, the traditional and static model under regulated market has been faced with the transition to a dynamic un-deterministic pattern and thus to an adaptive business model of real options, the so-called "adaptive management." Based on this model, it could be expected the dynamic adaptive design, planning, scheduling and operation of energy resources portfolio (state variable availability) will be achieved, and thus to be adaptive dynamic measurement (measured variable observability), adaptive analysis and evaluation (performance variable perceptible) and effective adaptive control of operating guidelines under the policy objectives (control of controllable variables). It covers value management, risk management, asset management and adaptive management hereby summarized as follows:

1) Value management: Under adaptive planning point of view (energy balance) of smart grid (adaptive energy resources portfolio infrastructure condition), it will be in the pursuit of adaptive energy resources portfolio value (energy, economy, environment 3E value under regulated or non-regulated market with energy policy), including reliability, economic effectiveness, and mitigation and adaptation under climate change.
2) Risk management: Under adaptive planning point of view (energy balance) of smart grid (adaptive energy resources portfolio infrastructure condition), it will be in the pursuit of adaptive energy resources portfolio risk (energy, economy, environment 3E risk under regulated or non-regulated market with energy policy), including operational risk, market risk, financial risk, and environmental risk.
3) Asset management: Under adaptive planning point of view (energy balance) of smart grid (adaptive energy resources portfolio infrastructure condition), it will be in the pursuit of adaptive infrastructure investment and operation of energy resources portfolio for value and risk, including smart grid, micro grid, virtual power plant, energy storage, etc.
4) Adaptive management: Dynamically apply real options to operational model of integrating adaptive value management, risk management and asset management, including the various combinations of real options such as extension vs deferral, choice vs abandonment and expansion vs contraction, etc.

D. Power Economics Implications

On the other hand, from the point of electricity economics, it's much more challenging for traditional power resource planning method (from static & deterministic load forecasting to the static & centralized power resource planning) to meet the basic requirement of instantaneous power scheduling & dispatch supply and demand balance under the impacts of many internal and external uncertainty factors (including demand side, supply side, price and policy, etc., especially the increasing renewable energy penetration ratio). Under such condition, it will be transformed to the parallel model under the portfolio of centralized & distributed supply resources with DSM, then in evolution to the smart grid model to adaptively dynamic integrate power portfolio, i.e. flexible dynamic "adaptive power economics". In all, on the power supply, it implies adaptive dynamic resources portfolio of flexible supply-side resources (centralized and distributed), demand-side resources (energy conservation and demand response) and regulating resources (energy storage and electric vehicles) under adaptive planning, including adaptive flexibility of power price and policy, as summarized below:

1) Adaptive renewable energy portfolio, including hydro, wind, solar, biomass, etc., gradually transform from supplementary energy to substituting non-renewable energy and become the main source of energy in the future.
2) Adaptive non-renewable energy portfolio, including traditional energy such as coal, gas and nuclear, gradually substituted by renewable energy and become supplementary source of energy in the future.
3) Adaptive renewable and non-renewable energy portfolio, with flexible coordinated scheduling & dispatch of uncontrolled and controlled energy portfolio.
4) Adaptive power demand and demand-side management, with dynamic flexible coordinated scheduling & dispatch demand-side management under changes in demand, including various energy conservation and demand response measures.
5) Adaptive micro-grid energy resources portfolio, with regional dynamic flexible coordinated scheduling & dispatch of distributed energy resources, including renewable energy, co-generation, micro turbines, etc.
6) Adaptive smart grid resources portfolio, with a comprehensive system dynamic flexible coordinated scheduling & dispatch centralized and distributed supply-side resources, demand-side resources, and regulating resources (energy storage and electric vehicles).
7) Adaptive power resource planning & operating reserves, the dynamic flexible planning, scheduling & dispatch under the flexible reserves to achieve 3E objectives for energy equilibrium.
8) Adaptive power price, the dynamic flexible electricity price under the equilibrium of energy and profit.
9) Adaptive policy, the dynamic flexible policy.

V. CONCLUSIONS

A. Overall Conclusions

Under weak adaptive scenario, traditional power resource planning is based on the so-called “serial” portfolio planning, and the supply is driven by demand. The carbon mitigation capability, adaptive capacity, and reserve margin are dependent on the adaptive development of energy resources portfolio described as the following: (1) increase of grid adaptive control capacity, (2) increase of adaptive renewable energy generation, (3) decrease of adaptive non-renewable energy generation, (4) increase of adaptive demand-side management resources, (5) decrease of adaptive carbon emissions from carbon asset management, and (6) increase of adaptive resources re-cycling and re-use. Relatively, the effects of such portfolio are: (1) low sustainable development capability, (2) low adaptation capability, and (3) high planning reserve or operating reserve margin.

Under medium adaptive scenario, integrated resource planning (IRP) is based on energy resources “parallel” to portfolio planning , with demand-side management as negative power source. In addition to enhancing the adaptive change of power infrastructure portfolio under parallel system structure, as described above, it also has limits on macro-economic development of power demand and adaptive change of industrial structure. Relatively, the effects of such portfolio are: (1) medium sustainable development (mitigation) capability, (2) medium adaptation capability, and (3) medium planning reserve or operating reserve margin.

By referring the model of adaptive control (3E coupled model) and on-line adaptive control (smart grid), theoretically and empirically, the construction of energy resource portfolio in both adaptive dynamic combination of low-carbon & smart in the face of the dynamic environment under the context of dramatic changes is established on the core of "network type" smart grid system with variable combination of energy resources portfolio design. It could instantly integrate the supply-side, demand-side and regulating resources under real time, real location and real scenario, which includes (1) demand response, (2) electric vehicles, (3) energy storage system paired with smart grid (family, regional, system for different levels of network) and energy management system, advanced metering infrastructure (AMI), and adaptive power pricing (real-time power pricing, regional power pricing, classified power pricing and green power pricing). Thus the flexible and dynamic adjustment of the above controllable & un-controllable energy resources can be adaptively planned & scheduled towards the consideration of the energy-economy-environment 3E adaptive integration of sustainable development and adaptive planning, design and operation. This is due to the consideration of energy resources use restrictions on carbon footprint of land ecological carrying capacity, as well as positive and negative performance feedback adaptive control effect. From the simulation results, it highlights the "path dependence" model of the dynamics of the emergence of a variety of adaptive control and behavioral characteristics of the power system, including: (1) basic mode (Mode 1-11) (2) the combination mode (mode 12-17) (3) uncertain mode (mode 18 and 21) (4) chaos mode (mode 22-24). Relatively, the effects of such portfolio are: (1) high sustainable development capacity, (2) high adaptation capacity, and (3) low planning reserve or operating reserve margin.

B. Recommendations

1) In the past, load forecast regards demand as certain (medium case), but this is not proper. Instead, demand should be a dynamically adaptive process and can be effectively managed by demand-side management.
2) In the past, long-term reserve margin (15%) and short-term operating reserve (10%) are defined as fixed amount, but this is also not proper. Instead, they should be flexibly adjusted through adaptive energy resources portfolio.
3) In the past, electricity price is considered as fixed, but this is not reasonable. When smart gird and pricing mechanism are effectively integrated, dynamic and adaptive pricing will prevail.

C. Study Limitations

1) The system dynamics simulation result developed by this paper is mainly focused on analysis of structure, direction, and development trend under mutual interaction and feedback of related variables.
2) The system dynamics simulation model developed by this paper has plenty room for improvement in the fields of verification, validation and accreditation of the model and data, so as it can conduct further quantitative analysis.
3) The simplified simulation model of this study is based on the power supply and demand balance principle under the energy balance and adaptive planning, scheduling & dispatch point of view under the second law of non-equilibrium thermodynamics. It implies many assumptions and complementary infrastructure. The power supply implies the reliability assumption (extended to ancillary services) of adaptive planning & operating reserve margin, the effect of demand-side management, and the mitigation and adaptive capacity of smart grid. This was simplified with structural coefficients, and further modeling can be done by adding mitigation and adaptive indicators. Renewable energy is a portfolio of various renewable energy resources, which implies complementary conditions of energy storage system and micro grid. Non-renewable energy is a portfolio of non-renewable energy resources, and more detailed modeling can be done in the future and extend to available energy or emergy further more. Profit represents the difference between costs (including fuel cost, power purchase cost and carbon cost) and benefits (power price revenue) under adaptive planning point of view, and it can be extended to wider and detailed scope in the future, and introduce value and risk indicators.

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