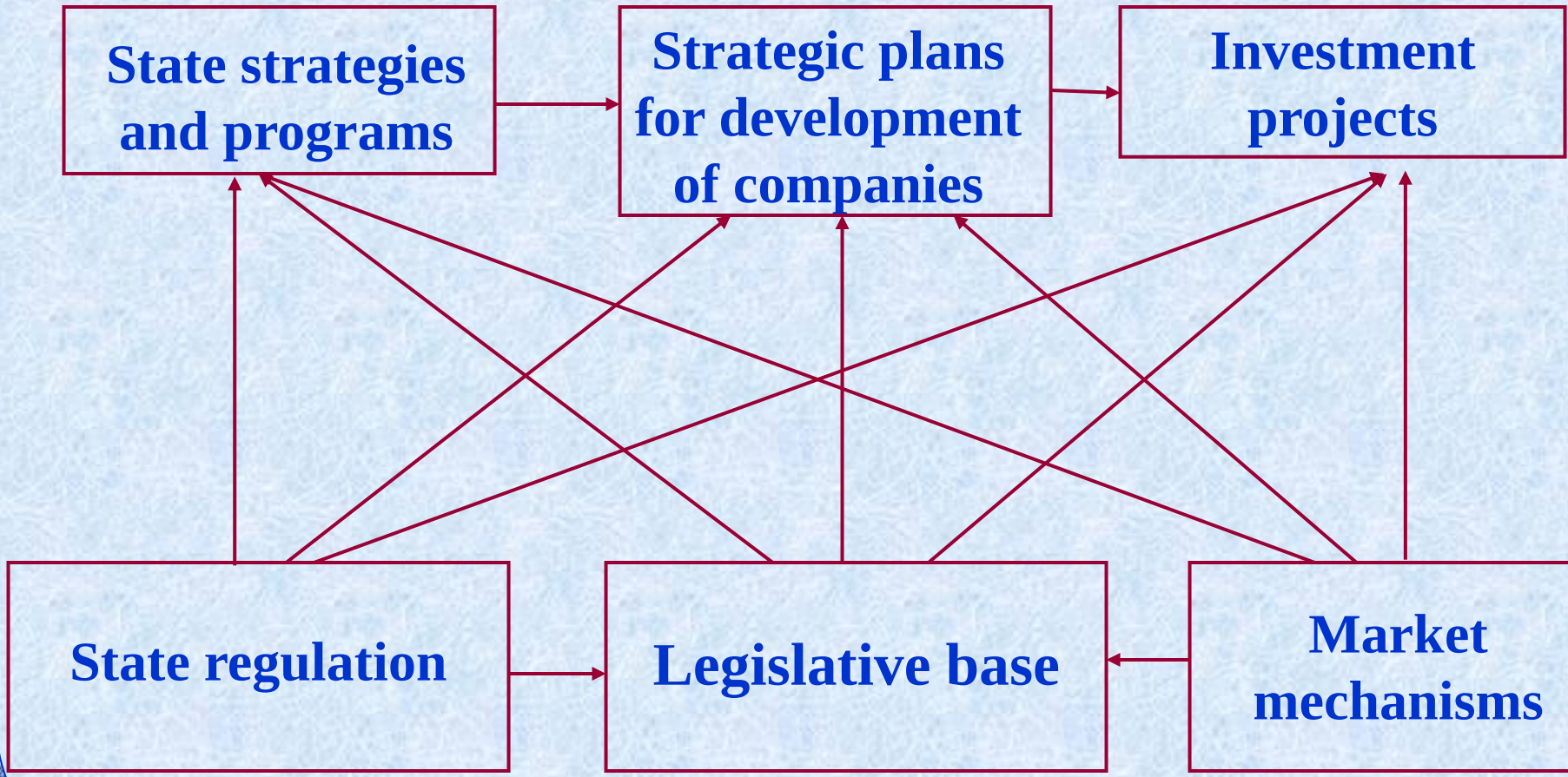
Multi-Criteria Decision Analysis Techniques in Electric Power System Expansion Planning

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Three Groups of EPS Expansion Planning Problems and Mechanisms of Decision Making



Interests of Subjects of Relations in Making Decisions on EPS Expansion

- *Electricity producers or/and sellers*
  - maximization of profit
- *Electricity consumers*
  - minimization of the tariffs for electricity
  - provision of electricity quality
  - provision of power supply reliability
- *Federal and regional authorities*
  - maximization of payments into budgets
  - minimization of environmental impacts
  - provision of the energy security
- *External investors*
  - minimization of the period for return of investments
  - maximization of dividends

Multi-Criteria Decision Analysis

- Application of multi-criteria utility functions
- Construction of the utility function for criteria by known procedures
- Estimation of weighting coefficients of the multi- criteria utility function
- Resulting criteria by different preference relations

Application of Multi-Criteria Utility Functions

Multi-criteria utility functions for *i*-th expansion option and *j*-th external condition on the *k*=1,*K* criteria

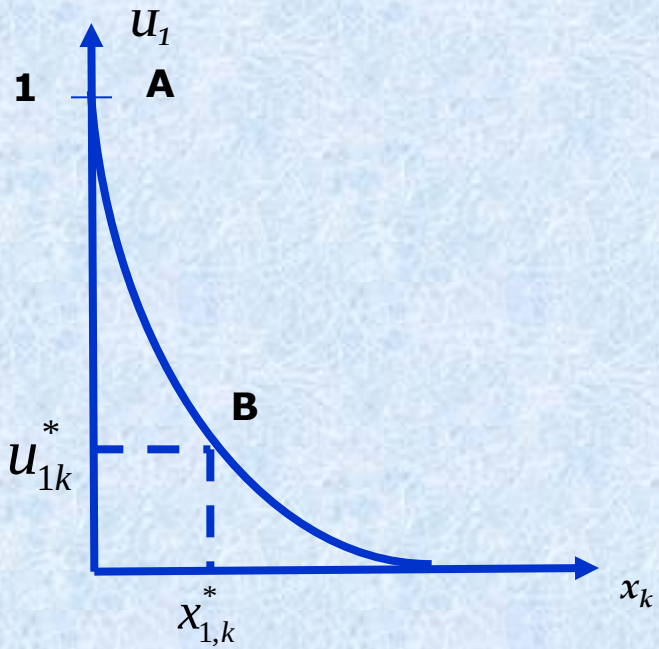
$$U_{ij} = \sum_{k=1}^{K} \lambda_k u_k(x_{ij}^k);\ i = \overline{1, I};\ j = \overline{1, J}.$$

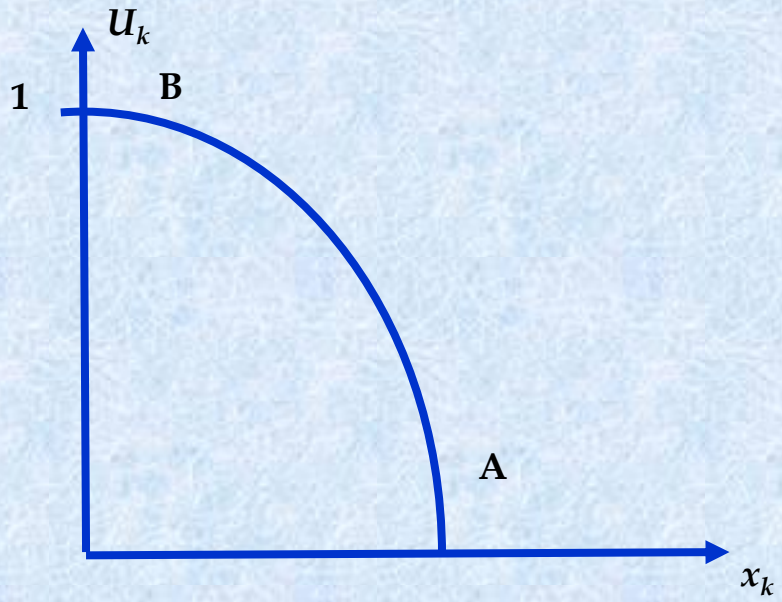
x_{ij}^k **- numerical estimation of expansion option**

For many external conditions

$$v_i = \sum_{j=1}^{J} p_j U_{ij};\ i = \overline{1, I}$$

Estimation of Weighting Coefficients of the Multi-Criteria Utility Function (1)





FOUR STEPS OF ALGORITHM

(1) The criteria are ranked by significance

(2) The value of the more significant criterion is fixed on the best level, the values of the others – on their worst levels

Estimation of Weighting Coefficients of the Multi-Criteria Utility Function (2)

3) The expert is asked the question: to what value x_{1k}^{*} he will agree to worsen the value of the more significant criterion to bring the value of each next criterion to the best level in turn. As the result

$$(1-u_{1k}^{*})\,\lambda_1=\lambda_k,\ \lambda_1\ \phi\ \lambda_k$$

The system of linear equations

$$\lambda_1/\lambda_k=1/(1-u_{1k}^{*});\ k=\overline{2,K};$$

$$\sum_{k=1}^{K}\lambda_k=1$$

cives all unknown $\lambda_k,\ k=\overline{1,K}$

Estimation of Weighting Coefficients of the Multi-Criteria Utility Function (3)

(4) The values of two first (by significance) criteria are fixed on their best levels, the remained values - on the worst. The system of linear equations

$$\lambda_2 / \lambda_k = 1/1 - u^*_{2k};\ k = \overline{3, K};$$

$$\sum_{k=2}^{K} \lambda_k = 1 - \lambda_1$$

gives $\lambda_k, k = \overline{2, K}.$

This step is considered as a test one. If estimations of λ_k **on the steps (3) and (4) are different, it is required to return to step (1) and to start inquiry of the expert concerning his preferences**

Resulting Criteria by Different Preference Relations

By probabilistic ideology

$$① \quad v_i^p = \sum_{j=1}^{J} p_j U_{ij}, \; i = \overline{1, I}$$

By risk ideology

$$② \quad v_i^r = \max_i \left\{ \min_j (p_j U_{ij}), i = \overline{1, I} \right\}$$

The solving system of *I*-1 equations

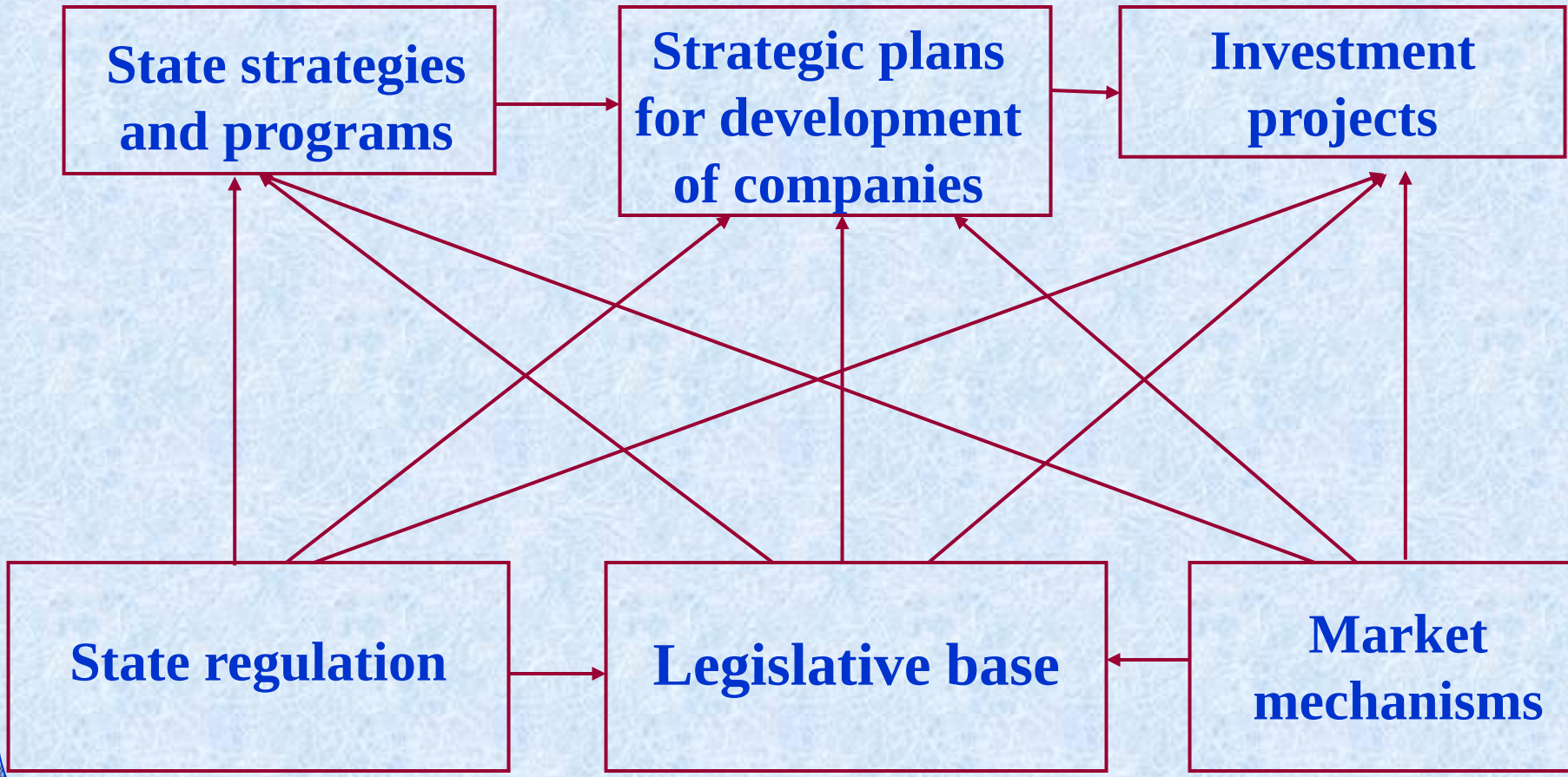
$$a_{i-m} v_i^p + (1 - a_{i-m}) v_i^r = a_{i-m} v_m^p + (1 - a_{i-m}) v_m^r,$$

$$i \neq m, \; i, m = \overline{1, I}, \; a_{i-m} \in [0; 1]$$

gives unknown a_{i-m}.

If we know a_{i-m} we can "weigh" decisions obtained by criteria ① and ② and determine when some option with the maximum utility ① cases to be the most preferable and some option with the maximum of utility ② becomes the most preferable

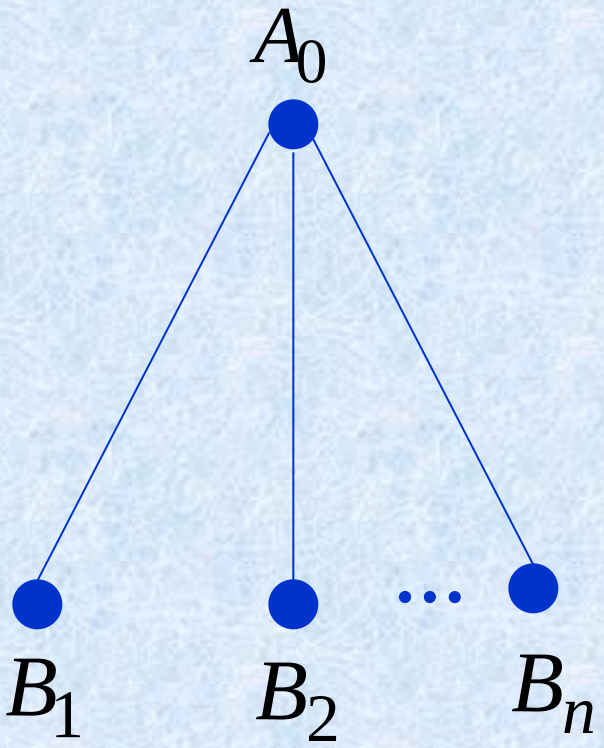
Three Groups of EPS Expansion Planning Problems and Mechanisms of Decision Making



The State Strategies and Programs of Power Industry Development

- Two-stage multi-criteria mathematical programming problems
- Hierarchical multi-criteria game problems
  - State – Power companies
  - State – Regions
  - State – Regions – Power Companies

General Hierarchical Approach



- Formation of state policy on power system expansion. Elaboration of stimulating mechanisms
- Making decisions of power companies taking into account state policy and neighboring companies

We have a set of *I*x*J* – dimensional matrices

$$X^k = \left\{ x_{ij}^k \right\},\ i = \overline{1, I};\ \ j = \overline{1, J};\ k = \overline{1, K},$$

where x_{ij}^k is a numerical estimation of the *i*-th expansion option by criterion *k*, provided the *j*-th external condition took place

The player A_0 chooses the system of regulation actions vectors

$$w = (w_1, \ldots, w_L)$$

from the set

$$W = \begin{cases} w = (w_1, \ldots, w_L): w_\lambda \geq 0; \;\; w_\lambda \in R^n \\ \sum_{\lambda=1}^{L} w_\lambda \leq b; \;\; b \geq 0 \end{cases}$$

Let $z = (z_1, ..., z_n)$ be an expansion option for the companies $B_1, ..., B_L$ The payoffs of these players by regulation action w_λ are supposed to be equal to

$$\lambda_l(z_l) \geq 0; \ \lambda = \overline{1, L}$$

The payoffs of the player A_0 is determined by the function

$$f(\lambda_1(z_1), ..., \lambda_L(z_L)) - g(w_1, ..., w_L) \geq 0$$

where $g(w_1, ..., w_L)$ characterizes the level of actions applied by the player A_0

The External Conditions for Two Developing Generating Companies

Scenarios	Power consumption	Fuel prices	Power exchanges
A	max	min	no
B	min	max	no
C	max	min	yes
D	min	max	yes

The criteria

α - investment costs

τ - current costs

β - budget (taxes)

γ - electricity tariffs

Initial Estimations of Options

Options	Utility and ranking (in brackets)	
	Company 1	Company 2
1	0.5284 (2)	0.2873 (4)
2	0.5154 (3)	0.6371 (2)
3	0.5302 (1)	0.5287 (3)
4	0.5117 (4)	0.7201 (1)

Newly Commissioned Capacities

Options	Additional capacities (MW)	Including WPP (MW)
2′, 3′, 4′	122	10

Expansion Options for Developing Companies

1 – commissioning of new coal-fired units

2 – commissioning of new gas-fired units

3 – partial commissioning of new coal- and gas-fired units

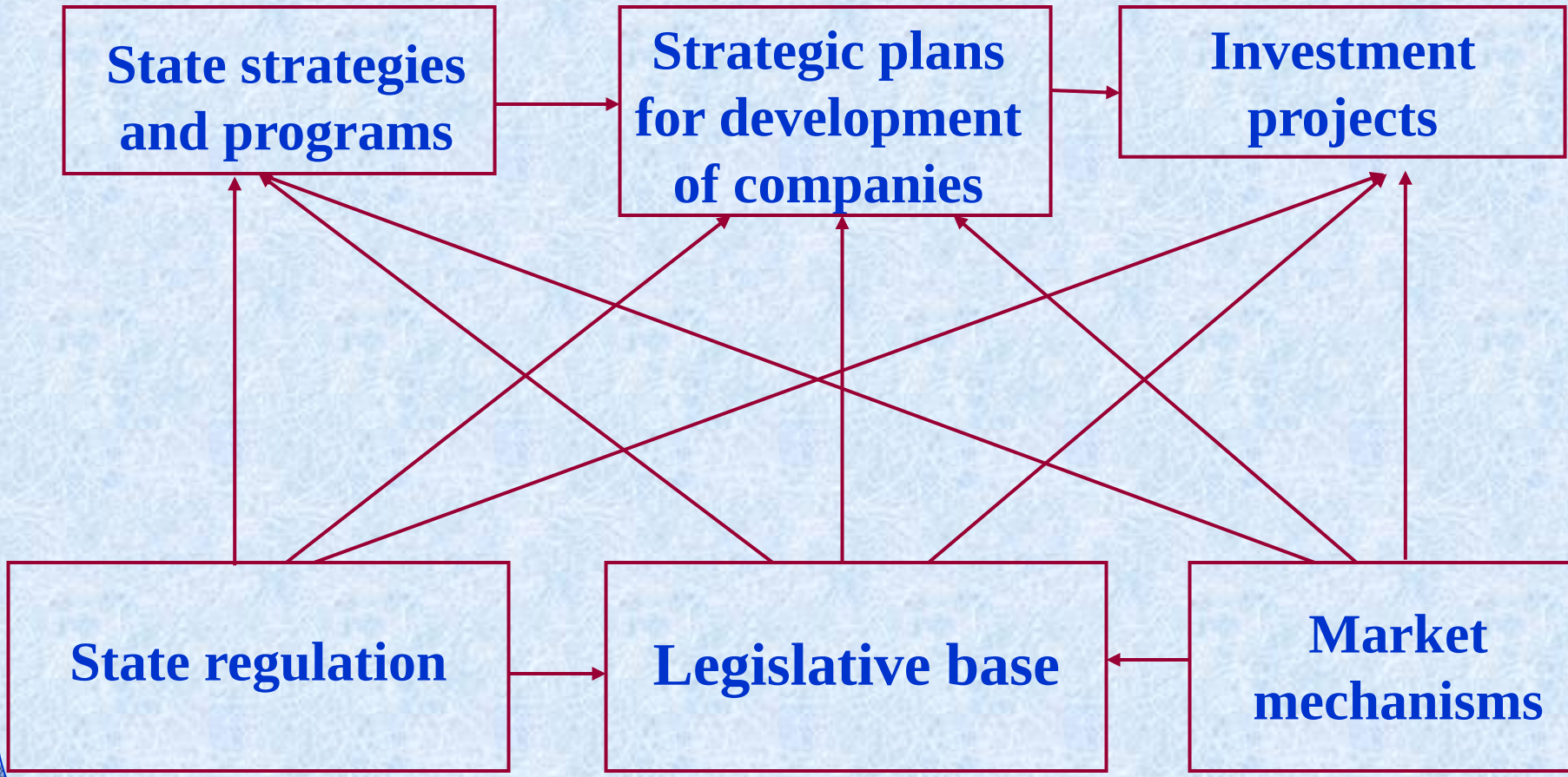
Calculation Results of the Accepted Solution Options for Company 1 at Specified External Conditions by the Criteria: Capital Investments and Current Expenditures

Criteria	Options	External conditions (for company 1)			
		A	B	C	D
α	4	170.3	170.3	1761.5	1761.5
	2′	192.3	192.3	1783.5	1783.5
	3′	182.3	182.3	1773.5	1773.5
	4′	179.3	179.3	1770.5	1770.5
τ	4	89.9	102.5	96.1	110.8
	2′	89.9	102.4	96.1	110.7
	3′	89.9	102.4	96.1	110.7
	4′	89.9	102.4	96.1	110.7

Comparison of Utilities for Expansion Options

Options	Utility
	Company 1
4	0.5117
2′	0.5107
3′	0.5115
4′	0.5117

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Strategic Plans for Development of Network Company

- ✶ Stochastic mathematical programming problem accounting uncertainty of strategies of producers and consumers (by Monte-Carlo technique)
- ✶ The games “against nature” accounting uncertainty of strategies of producers and consumers (by scenarios)
- ✶ Cooperative games in the case of generating companies coordination

Cooperative Game: Initial Conditions

Let: I be options of the EPS expansion

J be set of external conditions

K be criteria

$$X^k = \left\| x_{ij}^k \right\|, \quad i = \overline{1, I}; \quad j = \overline{1, J}; \quad k = \overline{1, K}$$

x_{ij}^k - a numerical estimation of the i-th expansion option by criterion k, provided the j-th external condition took place

The Shapley Value

$$\varphi_i(v) = \sum_{\substack{T \subset M \\ t \in T}} \frac{(t-1)!(m-t)!}{m!} [v(T) - v(T \setminus \{i\})]$$

$M = \{1, \ldots, m\}$ – a set of players

$T_i,\ i = \overline{1,\ M}$ - coalitions of the set M

t – number of players in coalition T

Two-Sided Shapley Value

$$\varphi_i(T_i, T_j)(T) = 0.5v(T_i) + 0.5(v(T) - v(T_j))$$

Coalition T_i and T_j are the bases of two-sided coalition T; v – characteristic function.

What is the Characteristic Function for the Shapley Value Estimation?

Multi-criteria utility function for, *i*-th expansion option and *j*-th external condition

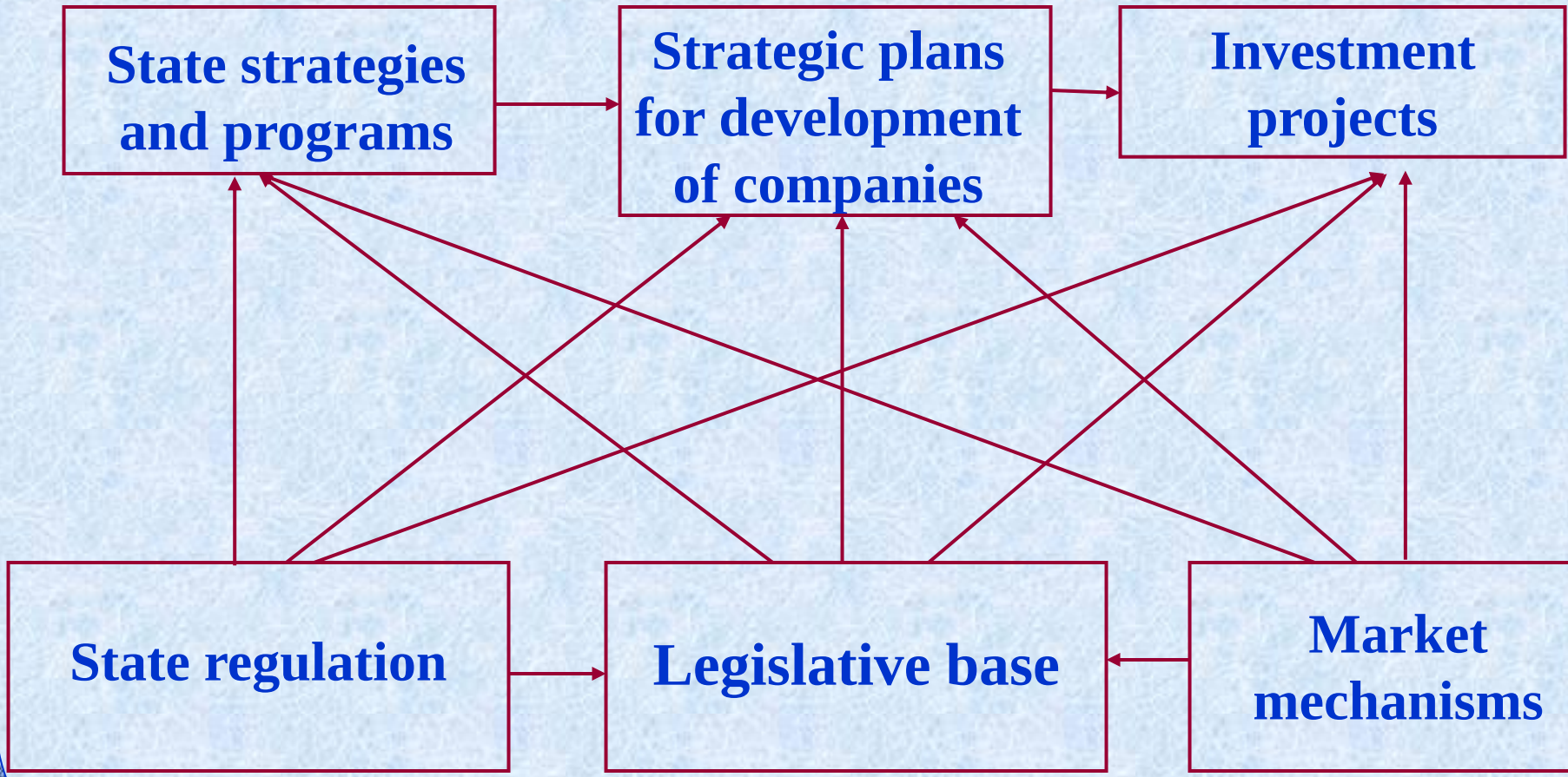
$$U_{ij} = \sum_{k=1}^{K} \lambda_k \, u_k \left(x_{ij}^k\right); \; i = \overline{1, I}; \; j = \overline{1, J}$$

and

$$v_i = \sum_{j=1}^{J} p_j U_{ij}; \; i = \overline{1, I}.$$

The multi-criteria utility function is the best characteristic function for the Shapley value estimation

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Making Decisions for Investment Projects

- Multi-criteria estimations in the case of self-investing
- Game problems in the case of independent investors

Conclusions

- In liberalized environment we deal with a great number of decision making problems for power systems (companies) expansion planning. These problems are not simple.
- Power systems companies expansion planning problems can be solved using mathematical programming or game- theoretical approaches or simulation estimations
- The development of technology and mathematical models and techniques for power system (company) expansion planning is very important task


Thank you very much
for your attention!