THE RELIABILITY ASSESSMENT PROJECT

George Gross

University of Illinois at Urbana–Champaign

PSERC Tele–Seminar

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PSERC

OUTLINE

- Review: scope and objectives
- Principal results
- Major findings
- Showcase study: Quantification of Market Performance as a Function of System Security

THE ACADEMIC PROJECT TEAM

- George Gross, UIUC Project Leader
- Sakis Meliopoulos, Georgia Inst. of Technology
- Richard Schuler, Cornell University
- Chanan Singh, Texas A&M University

THE INDUSTRY ADVISORS

- Ali A. Chowdhury, MidAmerican Energy
- Dale Krummen, AEP
- Eugene Litvinov, ISO New England
- Philip Hsiang, California ISO
- Mahendra Patel, PJM Interconnection,
- Tom Schmehl / Bob De Mello, New York ISO

SCOPE OF THE PROJECT

- Evaluation of reliability in the wider sense of adequacy and security of bulk power systems and in the context of *uncertainty management*
- Explicit consideration of the numerous and various changes under restructuring
- Capability to address the scale of grid reliability issues associated with the push toward grid regionalization

KEY OBJECTIVES

- To improve the representation of congestion situations in reliability evaluation
- To enhance the composite system modeling for reliability analysis through the explicit representation of operational considerations and economic aspects
- To develop computationally efficient tools for reliability evaluation of large systems
- To explicitly couple the reliability assessment with the analysis of the corresponding economics

PRINCIPAL RESULTS

- An improved understanding of the impacts of congestion on bulk power reliability
- An explicit evaluation of the impacts on system reliability of remedial actions and protection system hidden failures
- A useful scheme in security evaluation for the detection of island formation and the identification of causal factors under multiple line outages

PRINCIPAL RESULTS

- An explicit evaluation of the impacts of different security criteria on the market performance economics thereby providing the benefit/cost justification for a selected security criterion
- Design of a short−term resource adequacy program which takes into account both the physical and market factors that impact reliability
- Development of planning tools to optimally site generation resources taking into account congestion impacts

MAJOR FINDINGS

- The ability to detect island formation and identify the outaged lines that are the causal factors is a very useful tool in system security assessment online and off−line
- The demonstrated ability of the quadratized power flow in contingency simulation and effects analysis enabled the development of enhanced tools for reliability study

MAJOR FINDINGS

- The new approach for the systematic evaluation of economic impacts of a selected security criterion indicates that a power system may be operated under a stricter criterion without adversely impacting the economic efficiency of markets
- The value of electricity purchased, typically, far exceeds the average price paid; as such, the value of lost load exceeds, by many times, the price paid for electricity

MAJOR FINDINGS

- The reliability of electricity supplied over a network in terms of unanticipated interruptions and voltage and frequency stability have certain *public good* attributes, and therefore a central authority must establish their desired level
- In most cases, the provision of reliability – enhancing services may be decentralized and left to market forces with the prices paid to suppliers reflecting the proper values of public good aspects

MAJOR FINDINGS

- A carrots–and–sticks based approach for short–term resource adequacy is able to overcome some key deficiencies in the implemented schemes
- The importance of including outage costs in expansion planning has been clearly demonstrated with the advances in the location techniques proposed

MULTI – AREA SYSTEM SECURITY: THE ECONOMIC IMPACTS OF SECURITY CRITERION SELECTION

Teoman Güler

University of Illinois at Urbana – Champaign

PSERC Tele – Seminar

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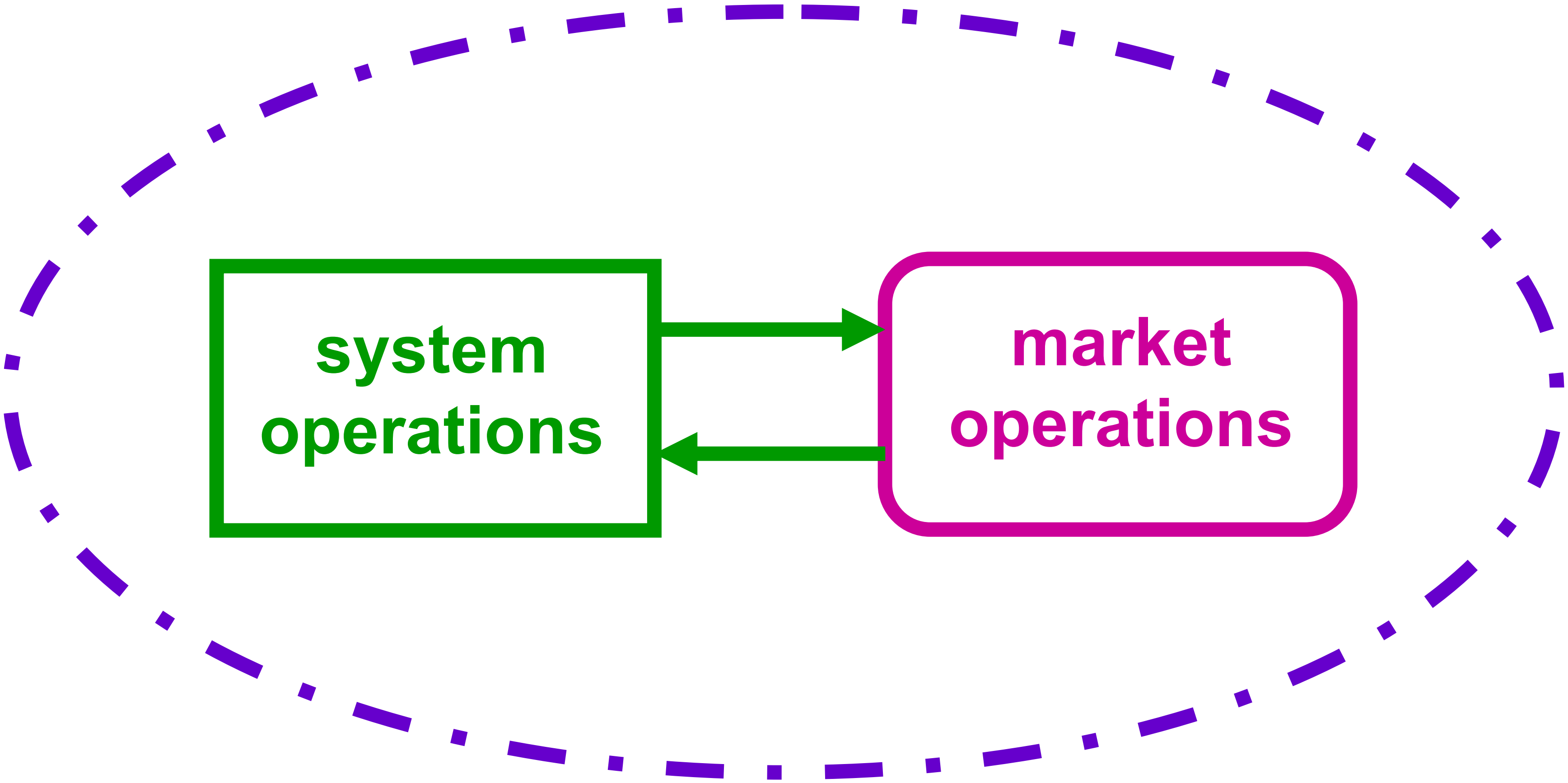
CONTEXT OF THE PROBLEM

- Steady − state system security
- Assessment of the performance of Day − Ahead Markets (DAM) and bilateral transactions
- Large − scale networks with multi − area systems
- Basic principle: the emulation of the way the RTO manages the system and market operations

OUTLINE

- Overview of the problem
  - physical network and DAM
  - role of security criterion
- Market performance quantification of a system snapshot
- Proposed approach
- Application study: the $\mathrm{ISO-NE}$ DAM
- Concluding remarks

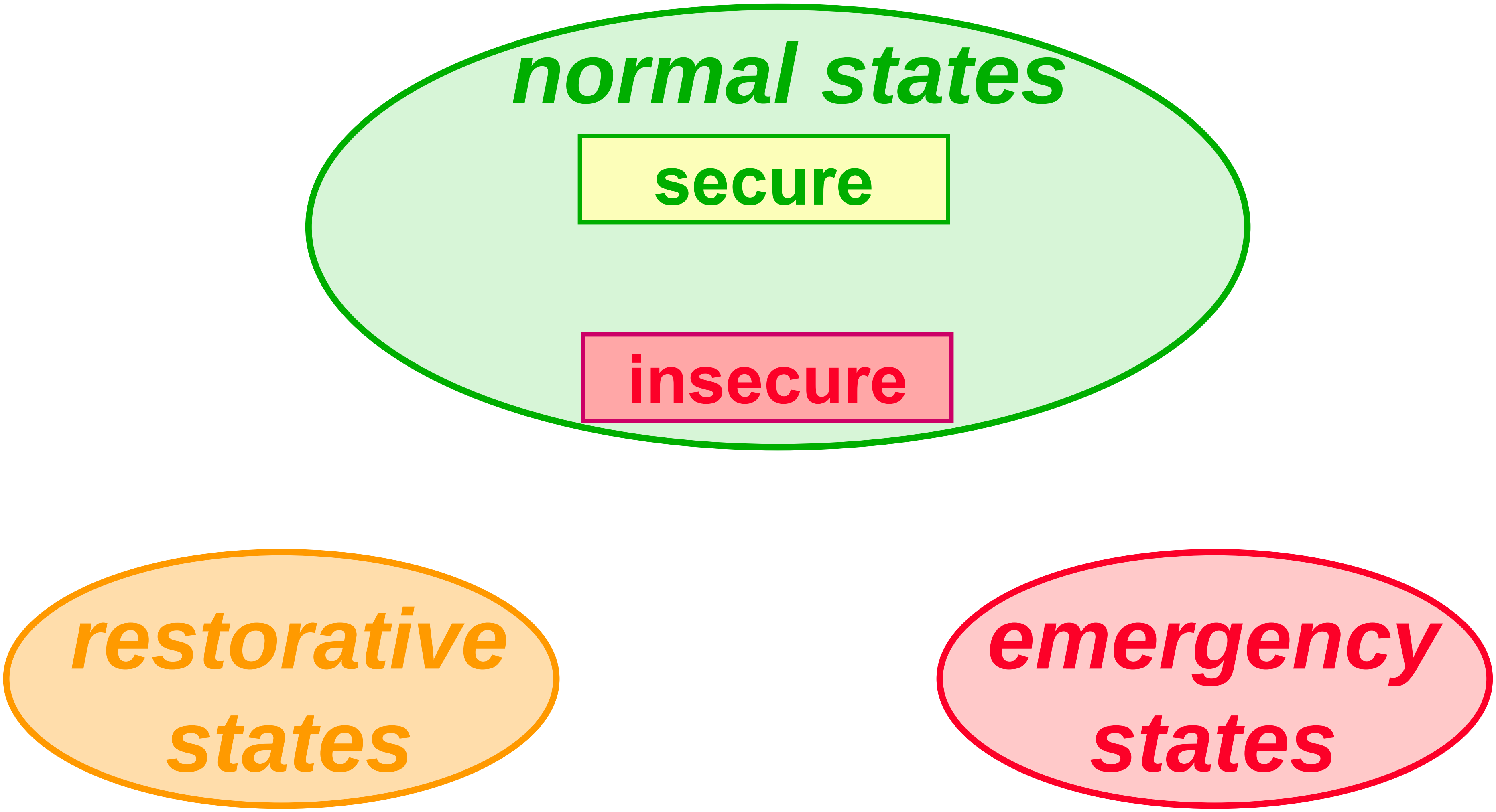
SYSTEM AND MARKET OPERATIONS



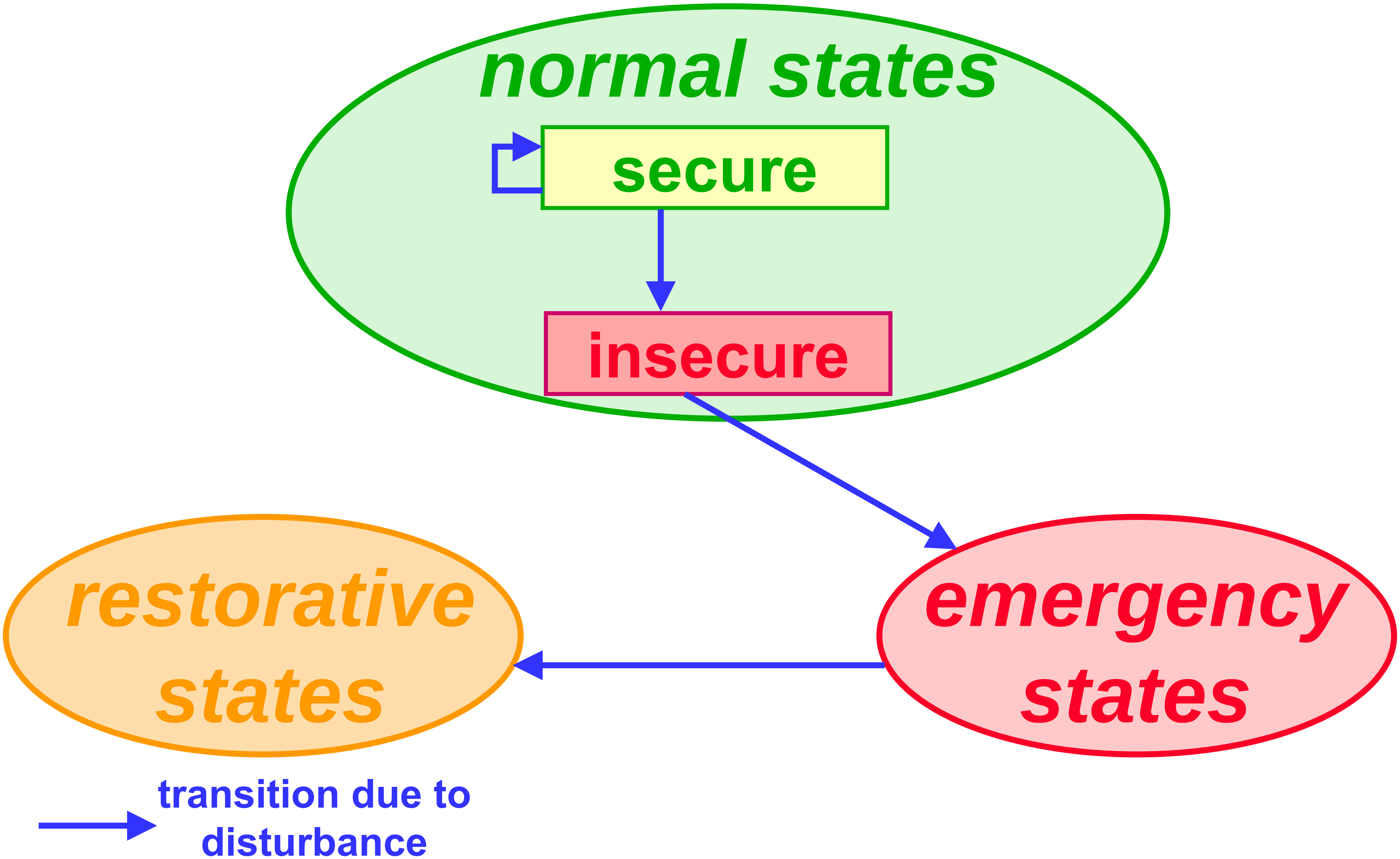
POWER SYSTEM SECURITY

- Power system security is the ability of the system to provide electricity with the appropriate quality under normal and disturbance conditions
- Power system security is an *instantaneous* condition: it is a function of time and of the robustness of the system with respect to imminent disturbances , referred as contingencies
- In security applications, we refer to the disturbances of interest as contingencies

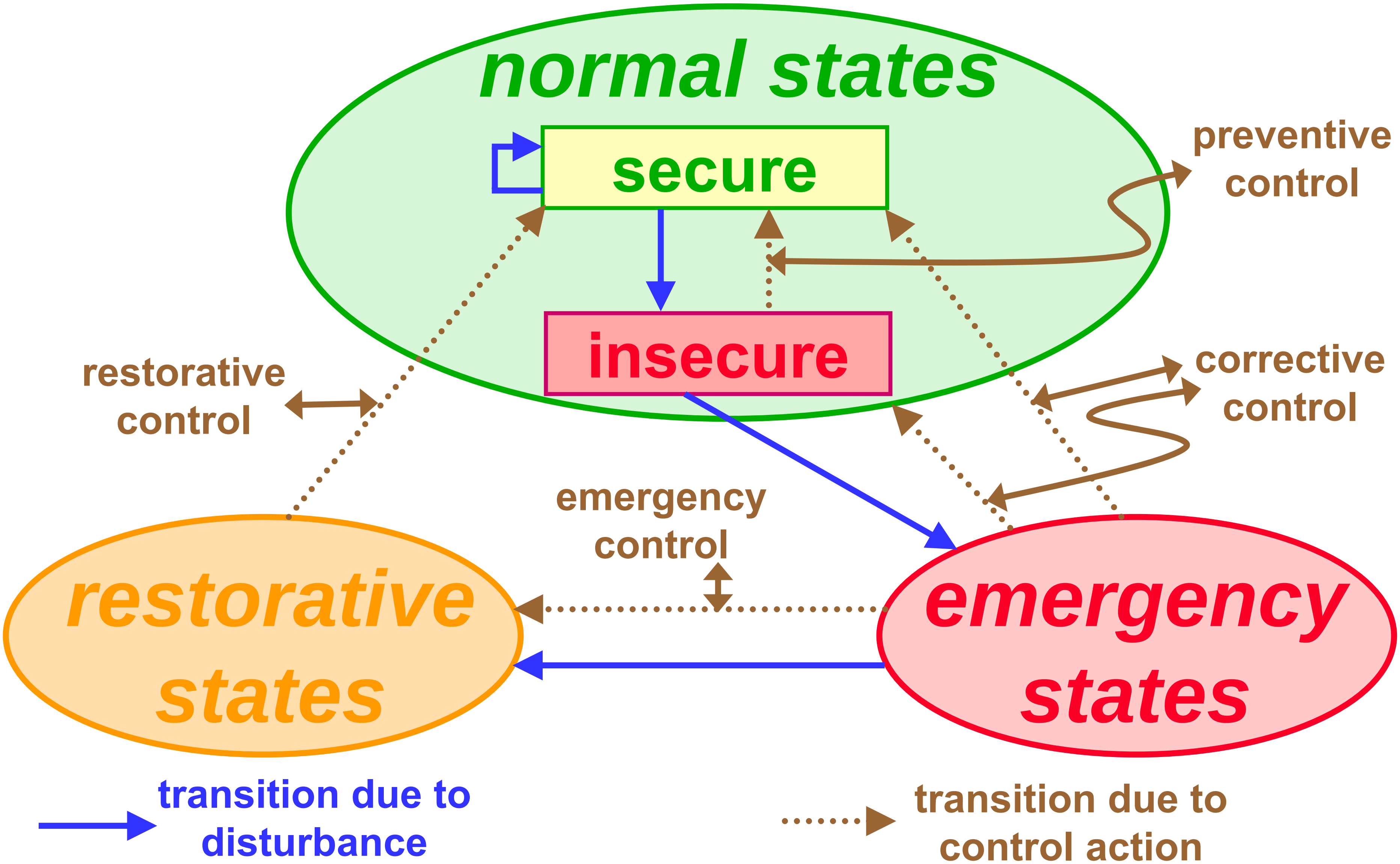
SECURITY FRAMEWORK



SECURITY FRAMEWORK



SECURITY FRAMEWORK



TYPICAL STEADY – STATE SECURITY CRITERIA

- **Deterministic criteria are used in system security assessments :**
  - n-1
  - n-2
- **The contingency sets associated with each security criterion are:**

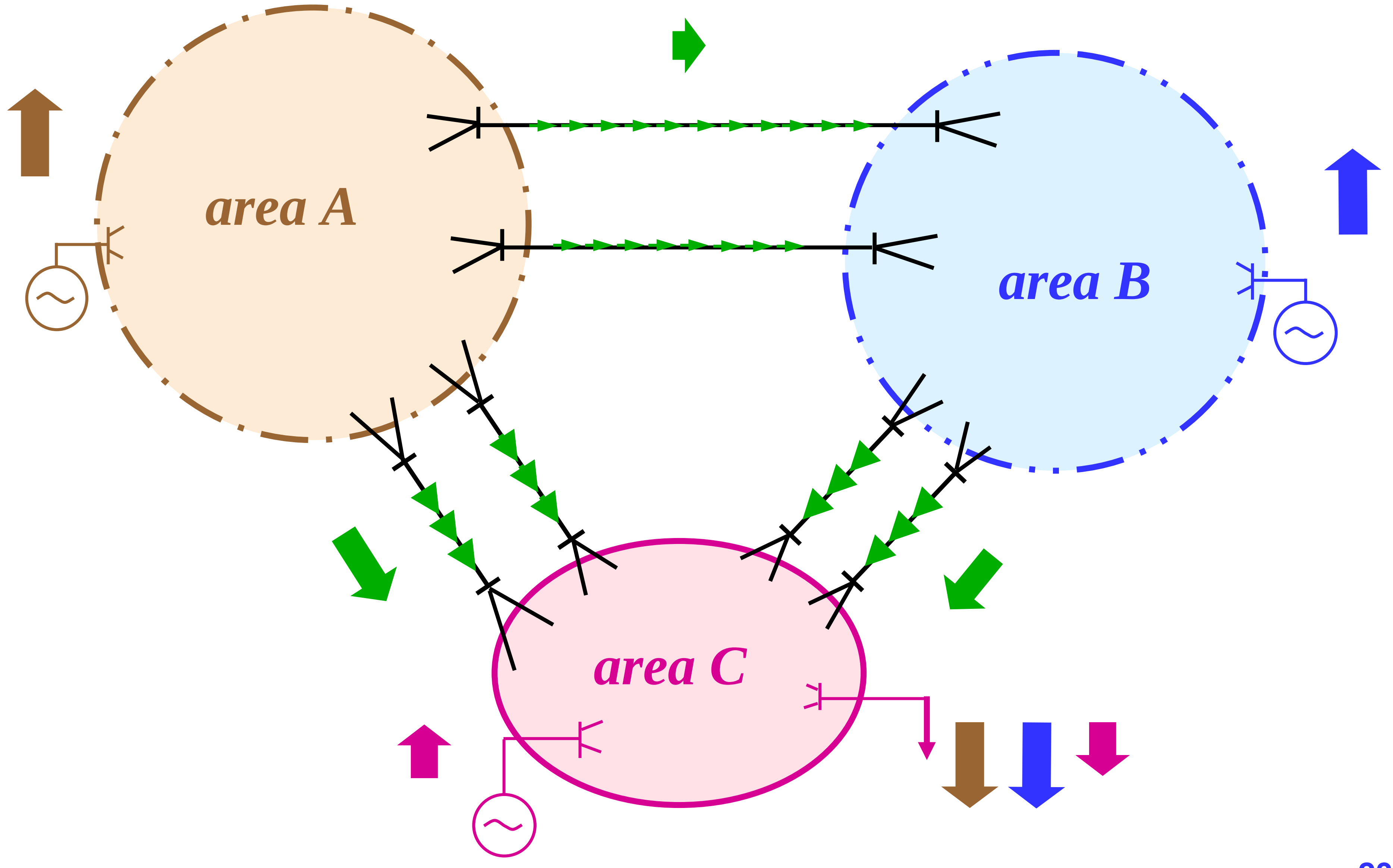
$$\mathscr{J}_{n\text{-}1} \triangleq \left\{ \boldsymbol{k}_j : \boldsymbol{k}_j \text{ is } \textit{the single element contingency} \right\}$$

$$\mathscr{J}_{n\text{-}2} \triangleq \mathscr{J}_{n\text{-}1} \bigcup \left\{ \boldsymbol{k}_j : \boldsymbol{k}_j \text{ is } \textit{the double element contingency} \right\}$$

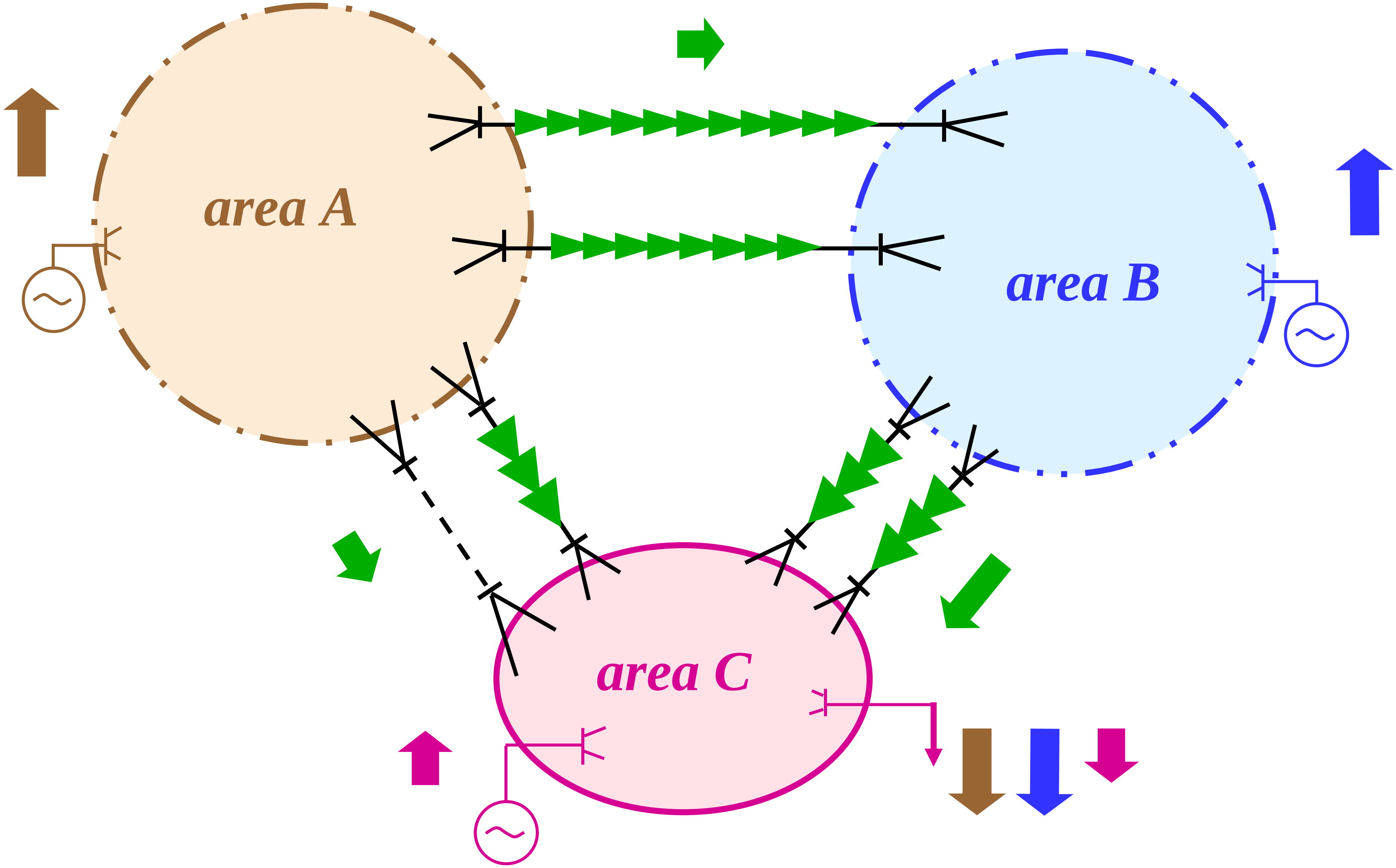
MULTI – AREA SYSTEMS

- Large – scale systems as encountered in RTOs consist of several areas interconnected via tie lines
- The transfer capabilities of the tie lines may constrain the utilization of certain resources
- The impacts of tie line outages may adversely affect system security

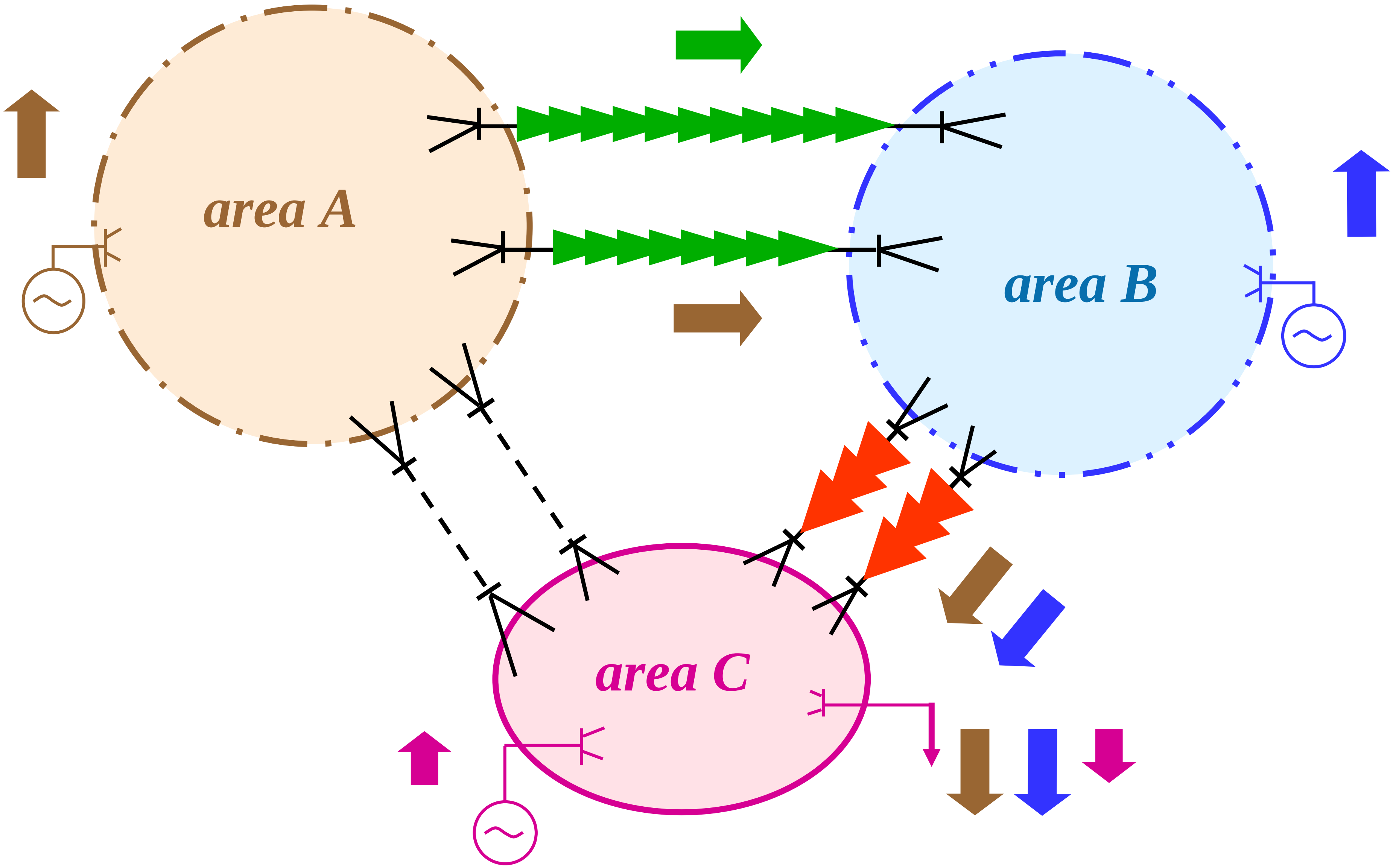
MULTI – AREA SYSTEM SECURITY



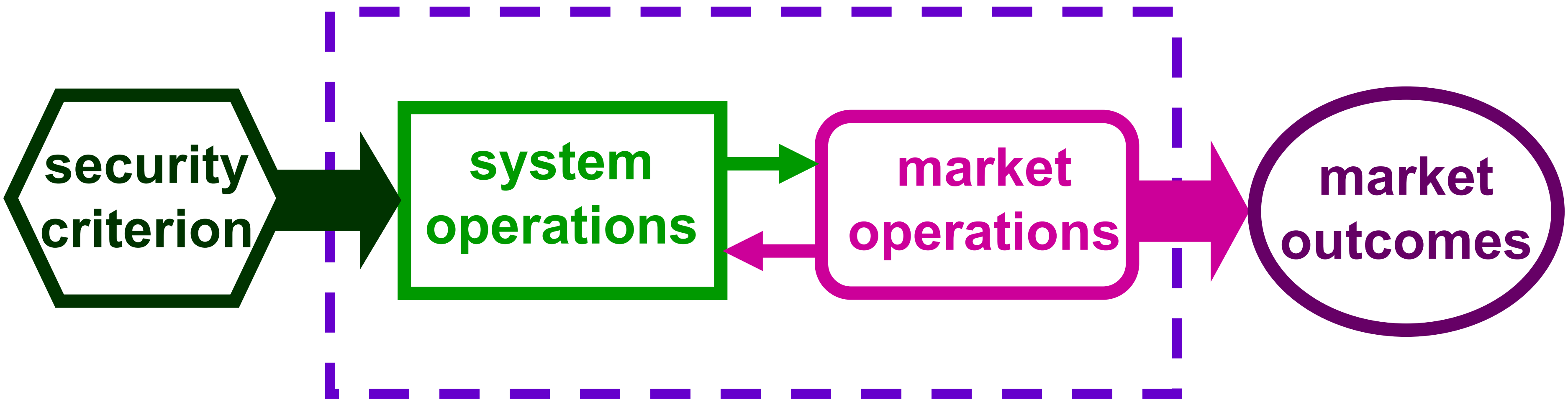
TIE LINE OUTAGE IMPACTS



DOUBLE TIE LINE OUTAGES: SECURITY CONTROL



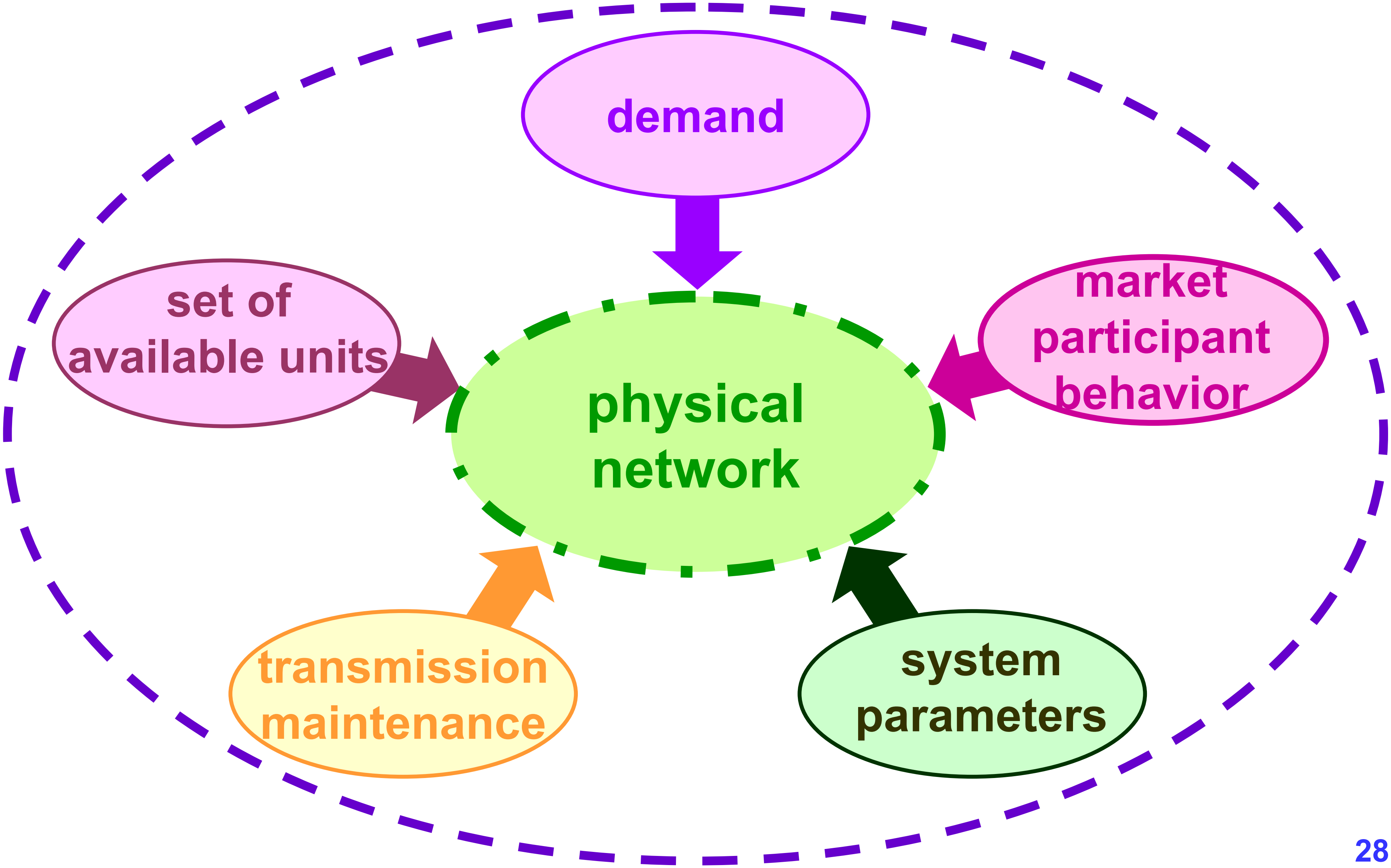
MARKET PERFORMANCE IMPACTS OF SECURITY CRITERION



SCOPE OF THE WORK

- Development of a general approach to quantify the monetary impacts of complying with a specified security criterion
- Quantification of the economic and the resource dispatch impacts of a change in security criterion
- Comparison of security control strategy impacts
- Investigation of the interactions among the areas

SYSTEM SNAPSHOT AT TIME *t*



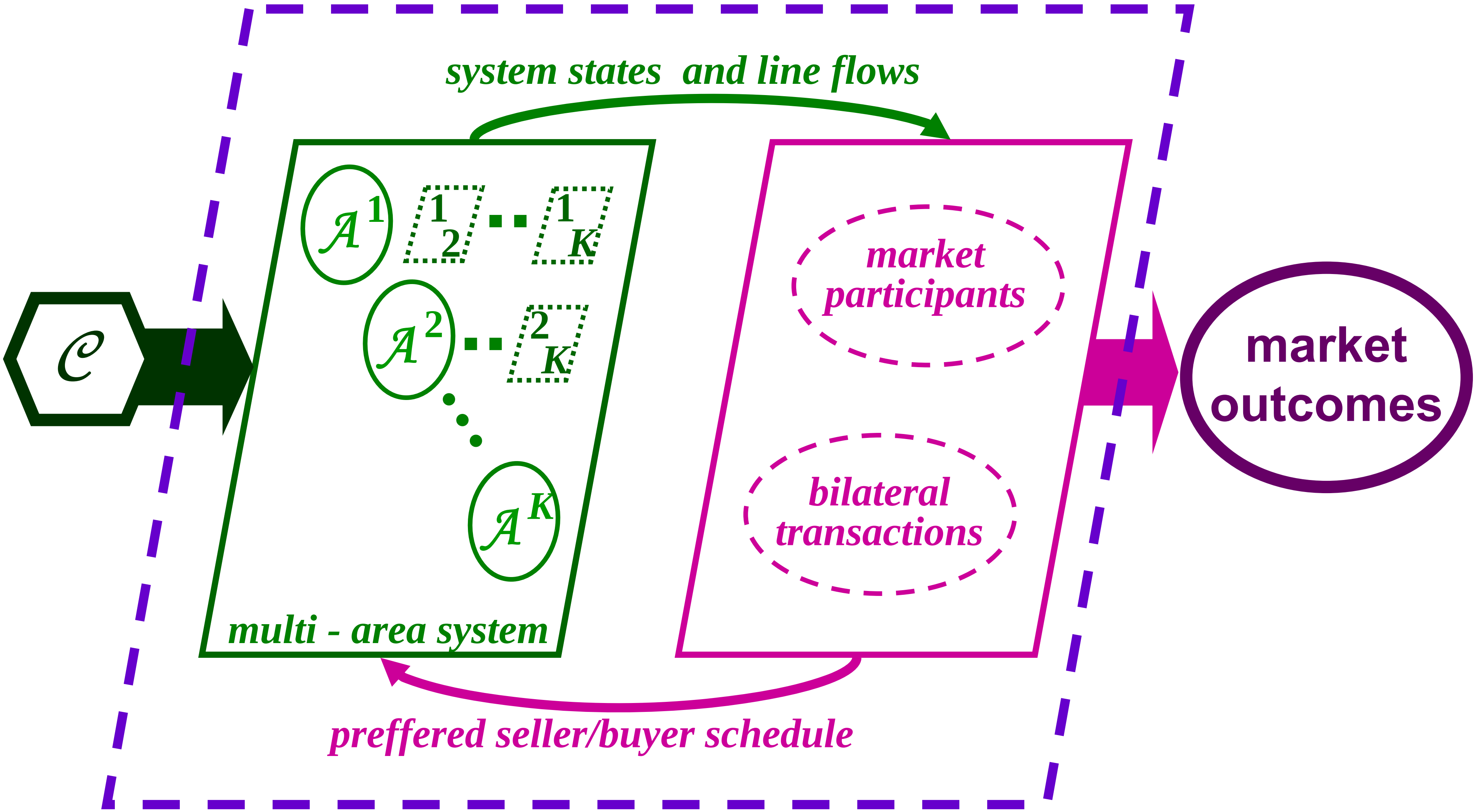
MARKET ASSESSMENT FOR A SYSTEM SNAPSHOT

- We emulate the way the *RTO* currently operates the markets and the system
- We quantify the market performance for a system snapshot under a specified security criterion
- Such quantification serves as the basic building block of the proposed approach

ASSUMPTIONS

- Unit commitment decisions fully reflect the requirements of the security criterion in force
- Ancillary services provision and acquisition requirements under the *RTO* framework do not impose any additional constraints on the system
- Bidding behavior of each market participant is independent of the security criterion in force

MARKET ASSESSMENT FOR A SYSTEM SNAPSHOT



SCOPF PROBLEM FORMULATION

$$\max \; S \triangleq \sum_{k=1}^{K}\left(\sum_{j=1}^{N^k}\beta_{b_j^k}\left(p_{b_j^k}^{(0)}\right)-\sum_{i=1}^{N^k}\beta_{s_i^k}\left(p_{s_i^k}^{(0)}\right)\right)+\sum_{w=1}^{W}\alpha_w\left(t_w^{(0)}\right)$$

s.t.

$$\underline{g}^{(0)}\left(\underline{p}_s^{(0)},\underline{p}_b^{(0)},\underline{t}^{(0)},\underline{\chi}^{(0)},\underline{\gamma}^{(0)}\right)=\underline{0}$$

$$\underline{h}^{(0)}\left(\underline{p}_s^{(0)},\underline{p}_b^{(0)},\underline{t}^{(0)},\underline{\chi}^{(0)},\underline{\gamma}^{(0)}\right)\leq\underline{0}$$

$$\left.\begin{aligned}
&\underline{g}^{(j)}\left(\underline{p}_s^{(j)},\underline{p}_b^{(j)},\underline{t}^{(j)},\underline{\chi}^{(j)},\underline{\gamma}^{(j)}\right)=\underline{0}\\
&\underline{h}^{(j)}\left(\underline{p}_s^{(j)},\underline{p}_b^{(j)},\underline{t}^{(j)},\underline{\chi}^{(j)},\underline{\gamma}^{(j)}\right)\leq\underline{0}\\
&\left|\underline{p}_s^{(j)}-\underline{p}_s^{(0)}\right|\leq\underline{\Delta p}_s^{(j)}\\
&\left|\underline{p}_b^{(j)}-\underline{p}_b^{(0)}\right|\leq\underline{\Delta p}_b^{(j)}\\
&\left|\underline{t}^{(j)}-\underline{t}^{(0)}\right|\leq\underline{\Delta t}^{(j)}
\end{aligned}\right\}\quad j\in\mathscr{J}_{\mathscr{C}}$$

SCOPF PROBLEM FORMULATION

$$\max \ \mathcal{S} \ \square \sum_{k=1}^{K}\left(\sum_{j=1}^{N^k}\beta_{b_j^k}\left(p_{b_j^k}^{(0)}\right)-\sum_{i=1}^{N^k}\beta_{s_i^k}\left(p_{s_i^k}^{(0)}\right)\right)+\sum_{w=1}^{W}\alpha_w\left(t_w^{(0)}\right)$$

s.t.

$$\underline{g}^{(0)}\left(\underline{p}_s^{(0)},\underline{p}_b^{(0)},\underline{t}^{(0)},\underline{\chi}^{(0)},\underline{\gamma}^{(0)}\right)=\underline{0} \quad \leftrightarrow \quad \underline{\lambda}^{(0)}$$

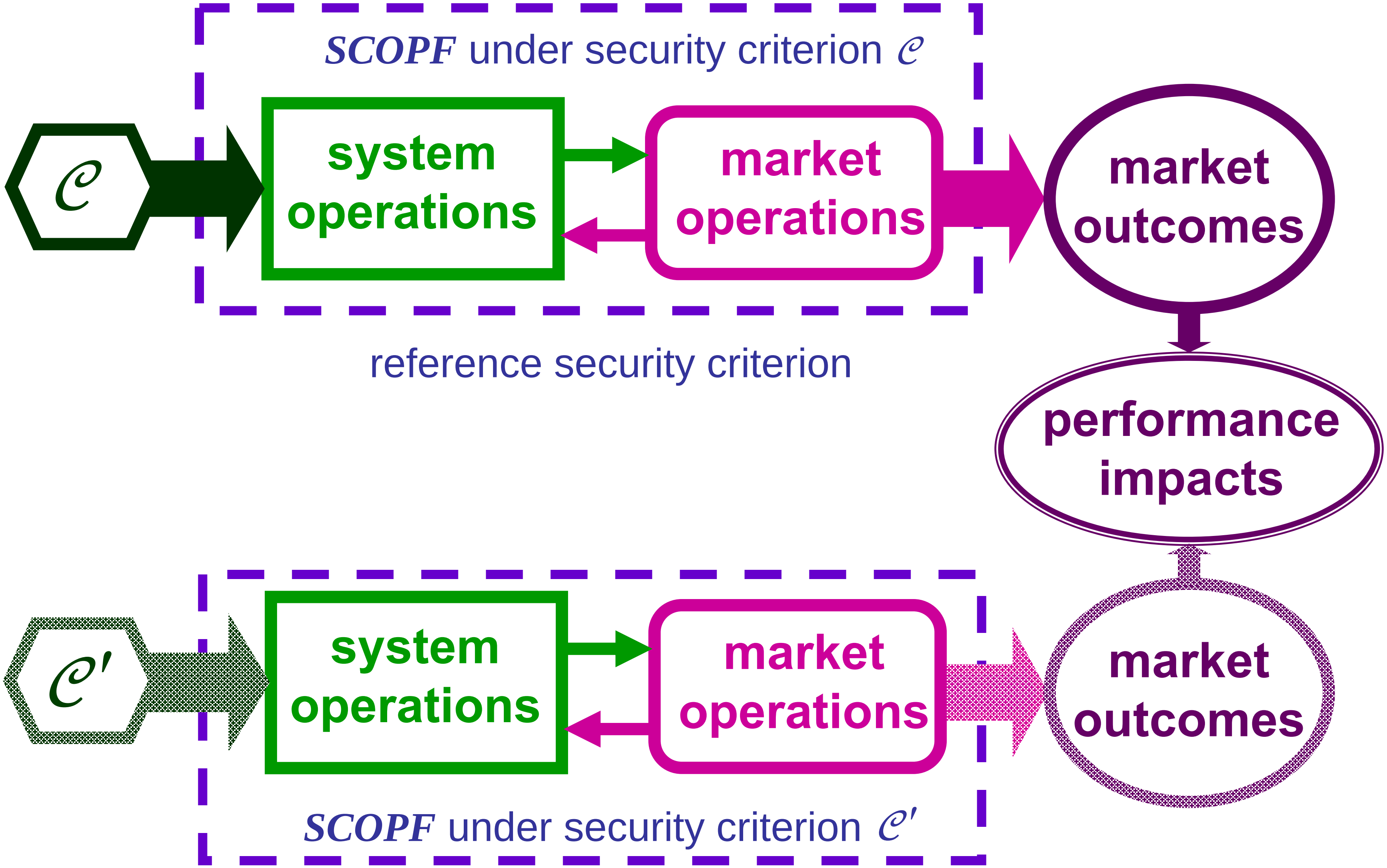
$$\underline{h}^{(0)}\left(\underline{p}_s^{(0)},\underline{p}_b^{(0)},\underline{t}^{(0)},\underline{\chi}^{(0)},\underline{\gamma}^{(0)}\right)\leq\underline{0} \quad \leftrightarrow \quad \underline{\mu}_h^{(0)}$$

$$\left.\begin{array}{ll}
\underline{g}^{(j)}\left(\underline{p}_s^{(j)},\underline{p}_b^{(j)},\underline{t}^{(j)},\underline{\chi}^{(j)},\underline{\gamma}^{(j)}\right)=\underline{0} & \leftrightarrow \quad \underline{\lambda}^{(j)} \\
\underline{h}^{(j)}\left(\underline{p}_s^{(j)},\underline{p}_b^{(j)},\underline{t}^{(j)},\underline{\chi}^{(j)},\underline{\gamma}^{(j)}\right)\leq\underline{0} & \leftrightarrow \quad \underline{\mu}_h^{(j)} \\
\left|\underline{p}_s^{(j)}-\underline{p}_s^{(0)}\right|\leq\underline{\Delta p}_s^{(j)} & \leftrightarrow \quad \underline{\mu}_s^{(j)} \\
\left|\underline{p}_b^{(j)}-\underline{p}_b^{(0)}\right|\leq\underline{\Delta p}_b^{(j)} & \leftrightarrow \quad \underline{\mu}_b^{(j)} \\
\left|\underline{t}^{(j)}-\underline{t}^{(0)}\right|\leq\underline{\Delta t}^{(j)} & \leftrightarrow \quad \underline{\mu}_t^{(j)}
\end{array}\right\} \quad j\in\mathscr{J}_{\mathscr{C}}$$

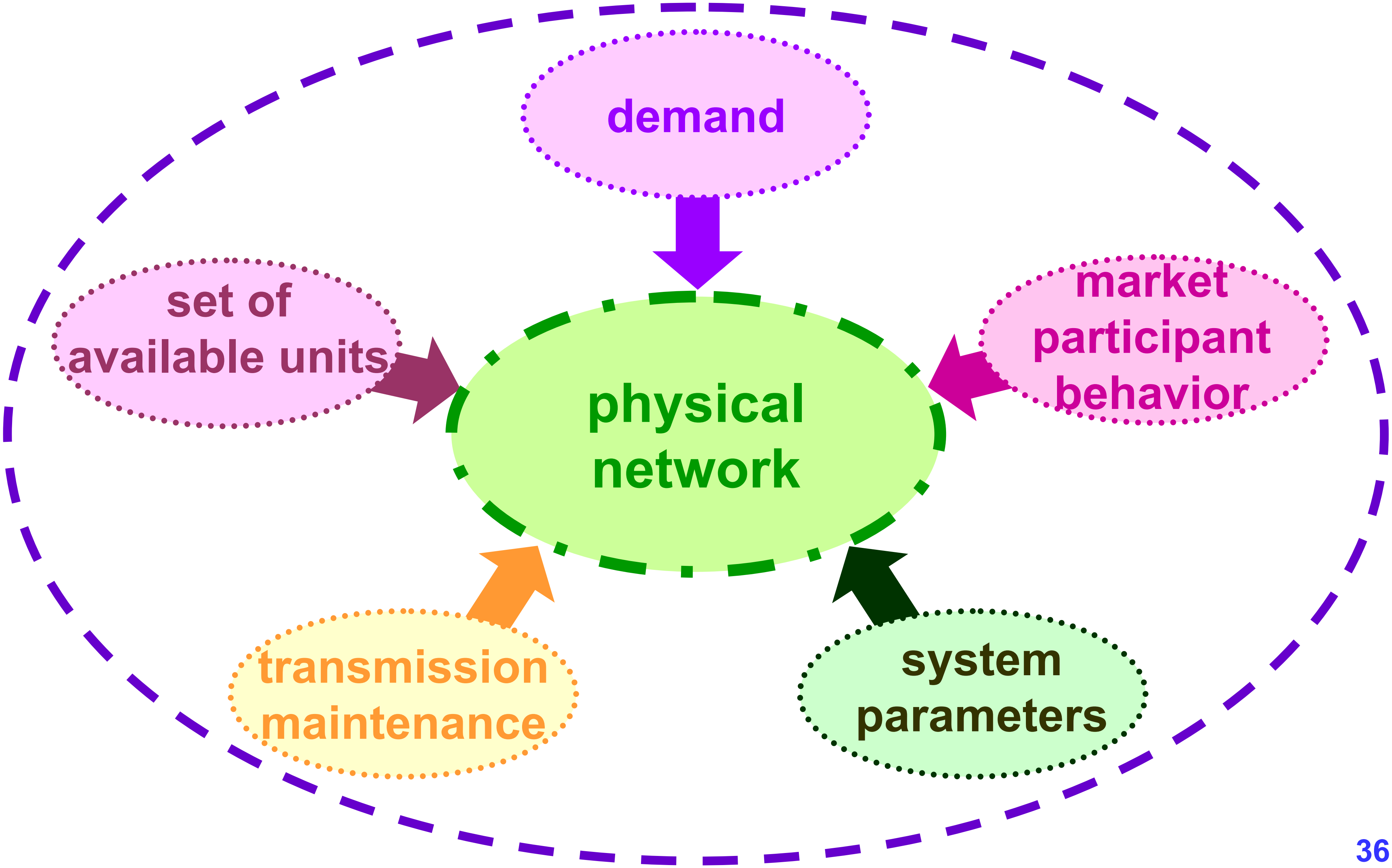
MARKET PERFORMANCE METRICS

system	$$\mathbf{S}\Big|_{\mathcal{C}} = \sum_{k=1}^{K} \mathbf{S}^{k}\Big|_{\mathcal{C}}$$	$
area	$$\mathbf{S}^{k}\Big|_{\mathcal{C}} \square \sum_{i=1}^{N^k} \Big[\beta_{b_i^k}\big(p^{*(0)}_{b_i^k}\big) - \beta_{s_i^k}\big(p^{*(0)}_{s_i^k}\big) \Big] \Big|_{\mathcal{C}}$$	
system	$$P\Big|_{\mathcal{C}} \square \sum_{k=1}^{K} \sum_{i=1}^{N^k} \Big[p^{*(0)}_{b_i^k} + \sum_{w=1,\, i=n_w \in \mathcal{N}^k}^{W} t^{*(0)}_{w} \Big] \Big|_{\mathcal{C}}$$	MW
area	$$P^{k}\Big|_{\mathcal{C}} \square \sum_{i=1}^{N^k} \Big[p^{*(0)}_{s_i^k} - p^{*(0)}_{b_i^k} + \sum_{\substack{w=1 \\ i=m_w \in \mathcal{N}^k}}^{W} t^{*(0)}_{w} - \sum_{\substack{w=1 \\ i=n_w \in \mathcal{N}^k}}^{W} t^{*(0)}_{w} \Big] \Big|_{\mathcal{C}}$$	

QUANTIFICATION OF SECURITY CRITERION CHANGE IMPACTS



CHANGES OVER TIME



MULTIPLE SNAPSHOT EXTENSION

- We apply the snapshot conceptual structure to each hour of the representative days for each specified criterion
- We quantify the hourly impacts and quantify the system and area − wide $\$$ as well as MW impacts on a daily, monthly and period basis
- The daily figures also serve to evaluate key statistics for each month such as mean, variance and range

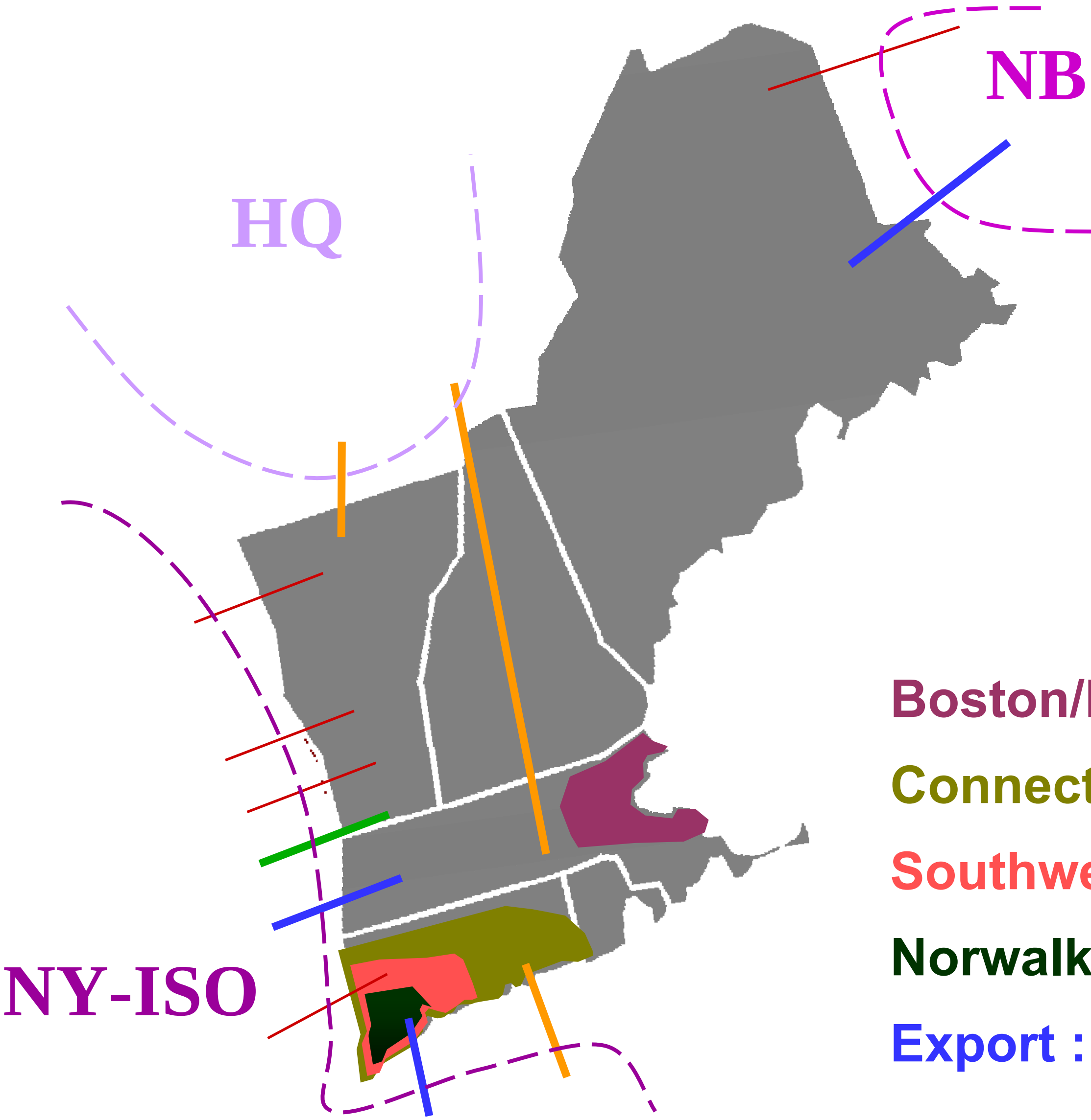
PROPOSED APPROACH SUMMARY

- The proposed approach quantifies the monetary impacts of complying with a specified security criterion
- This approach is deployed to simulate the hourly decision in the *DAM*: key idea in the simulation is the emulation of the way the *RTO* manages the system and market operations
- The proposed approach can be used to study a specified period of time

APPLICATION EXAMPLE: ISO−NE *DAM*

- We illustrate the application of the proposed approach on the ISO−NE *DAM* to quantify the performance impacts of operating the system under different system security criteria
- We use the historical day−ahead data – the system model and the bids/offers submitted – with the actual market clearing methodology

ISO−NE



Boston/Northeast Massachusetts : $\mathcal{A}^1$

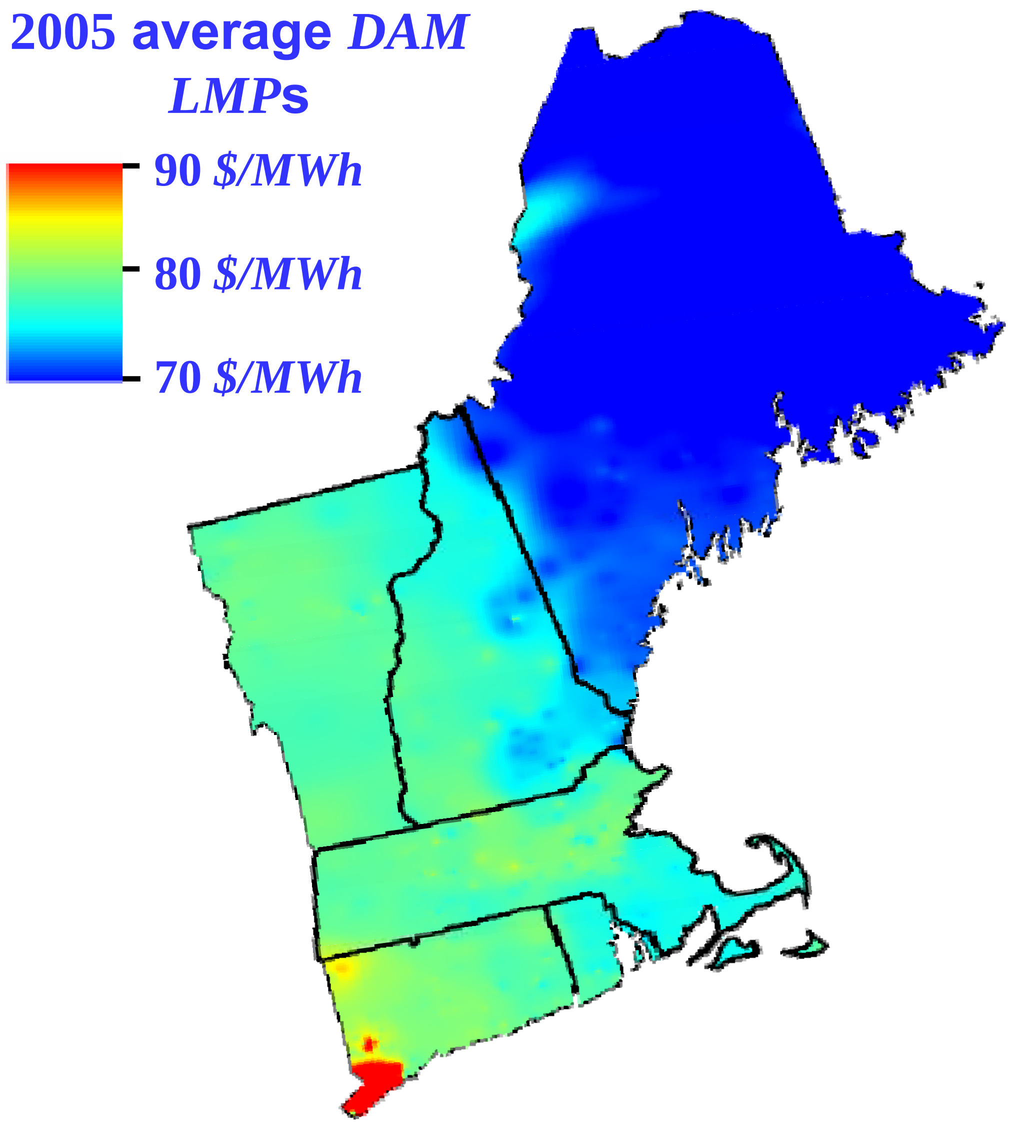
Connecticut : $\mathcal{A}^2$

Southwest Connecticut : $\mathcal{A}^3$

Norwalk/Stamford : $\mathcal{A}^4$

Export : $\mathcal{A}^5$

ISO–NE *DAM*



- 280 + participants
- 350 generators
- 31,000 + MW installed capacity
- peak demand: 26,885 megawatts on July 27, 2005

Source: ISO-NE, 2005 Annual Markets Report

THE SCOPE OF THE ISO–NE STUDY

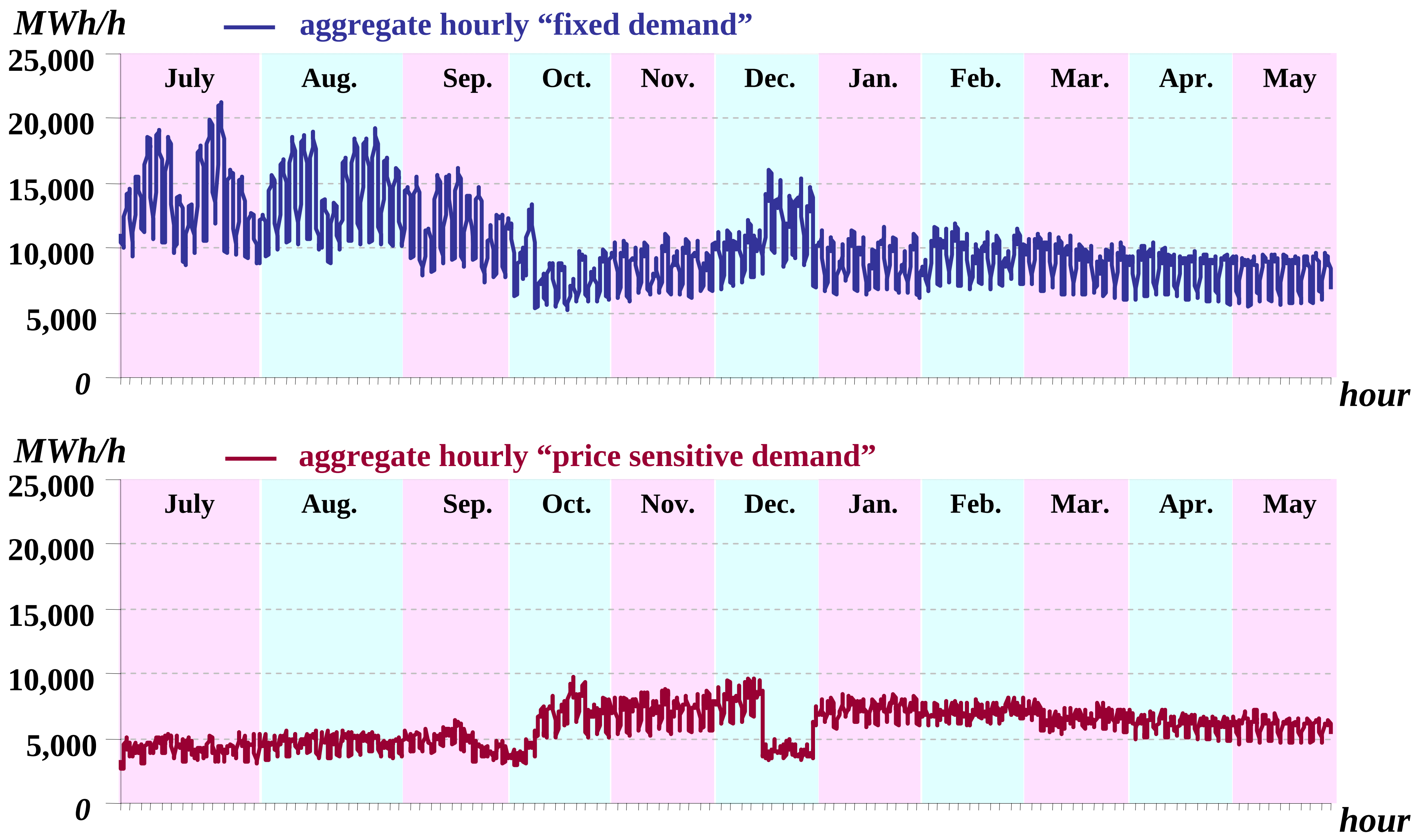
- Contingencies: transmission line outages
- Studied criteria:

security criterion	contingencies	
	single element	double element
$\mathcal{C}_1$	preventive	---
$\mathcal{C}_0$	preventive	corrective
$\mathcal{C}_2$	preventive	preventive

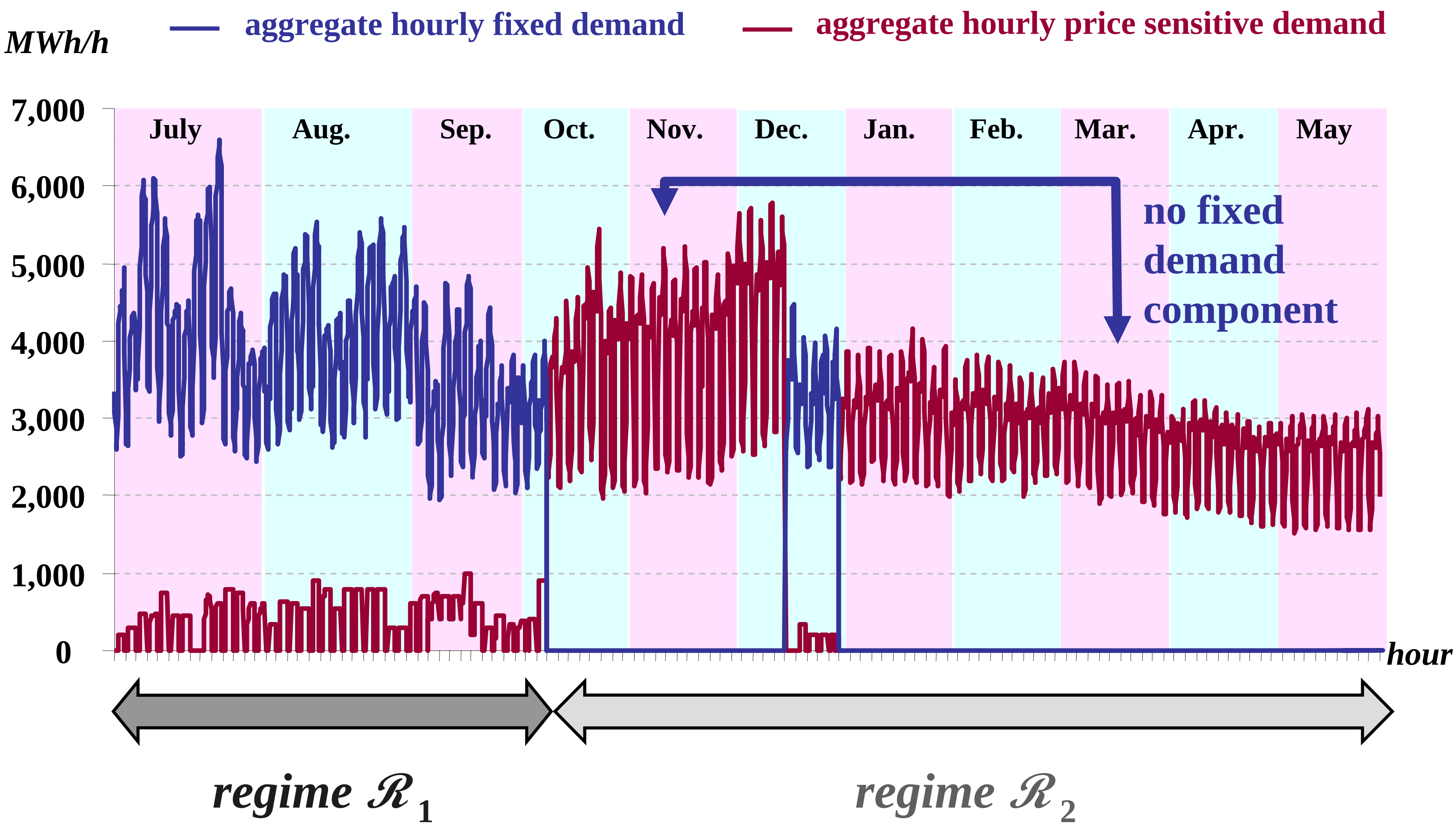
reference criterion → $\mathcal{C}_0$

- Study period: July 2005 – May 2006 , 118 *DAM* representative days

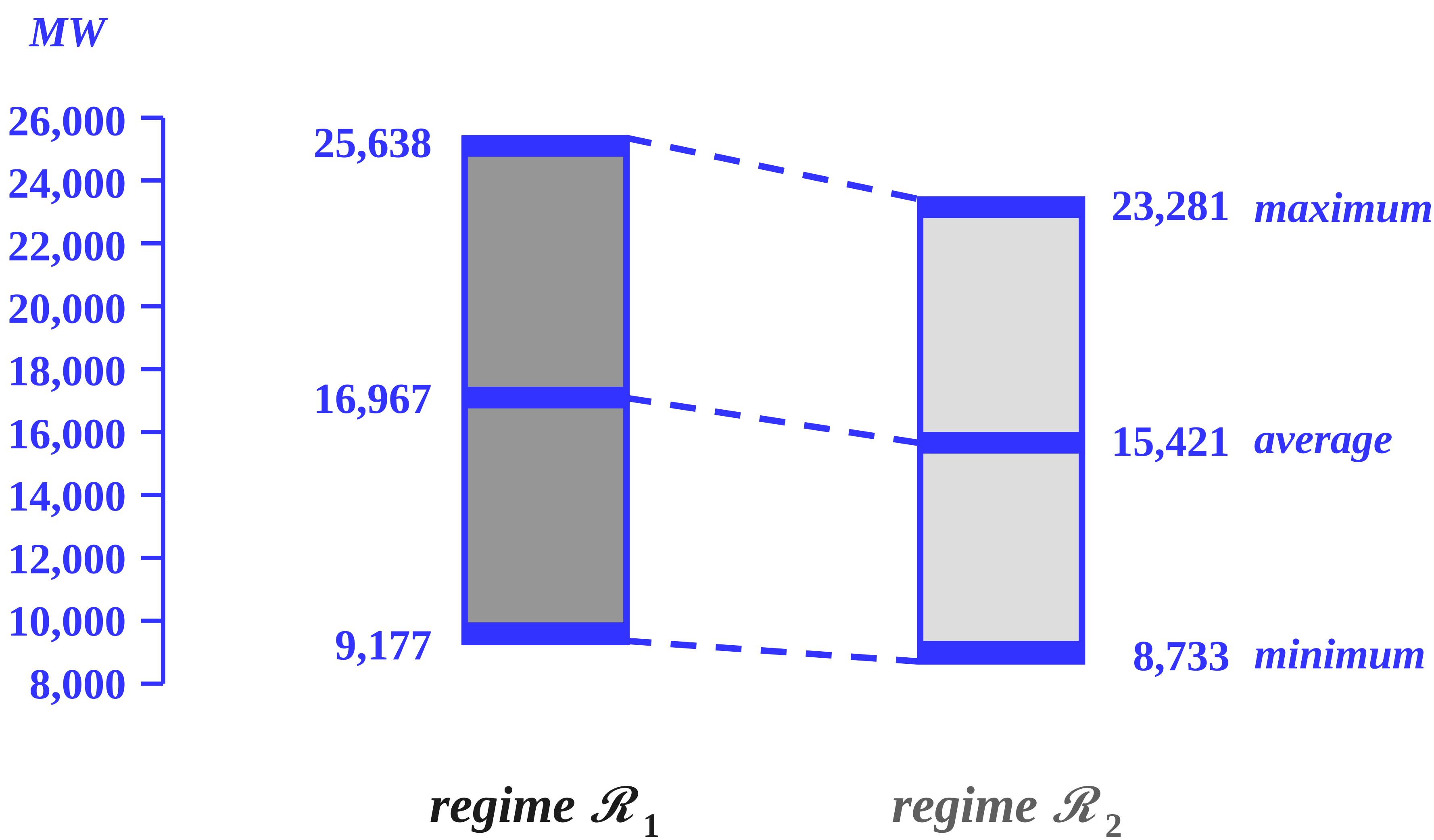
TOTAL DEMAND OF THE BIDS



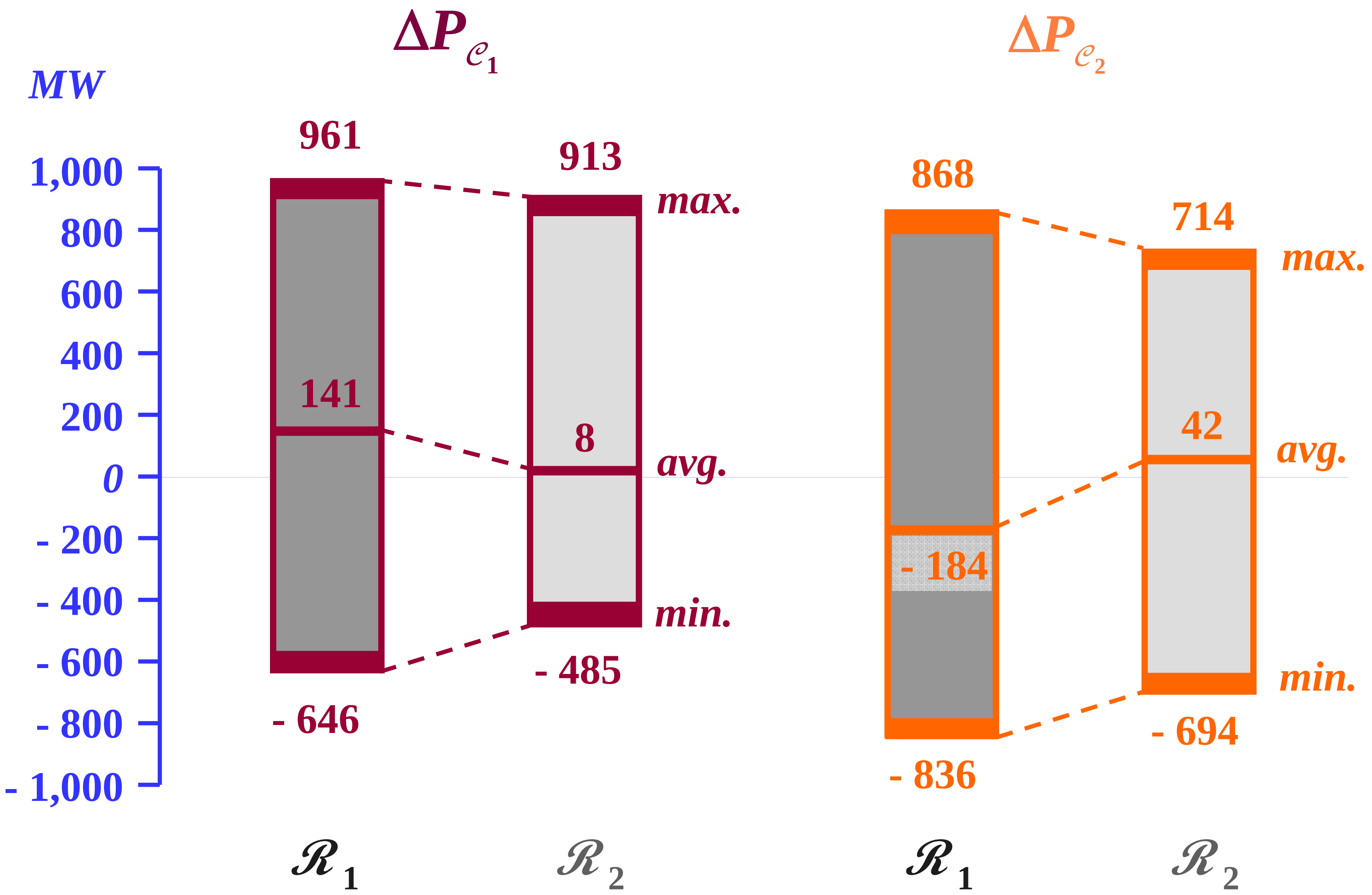
THE BIDDING PATTERN OF A SINGLE LARGE BUYING ENTITY



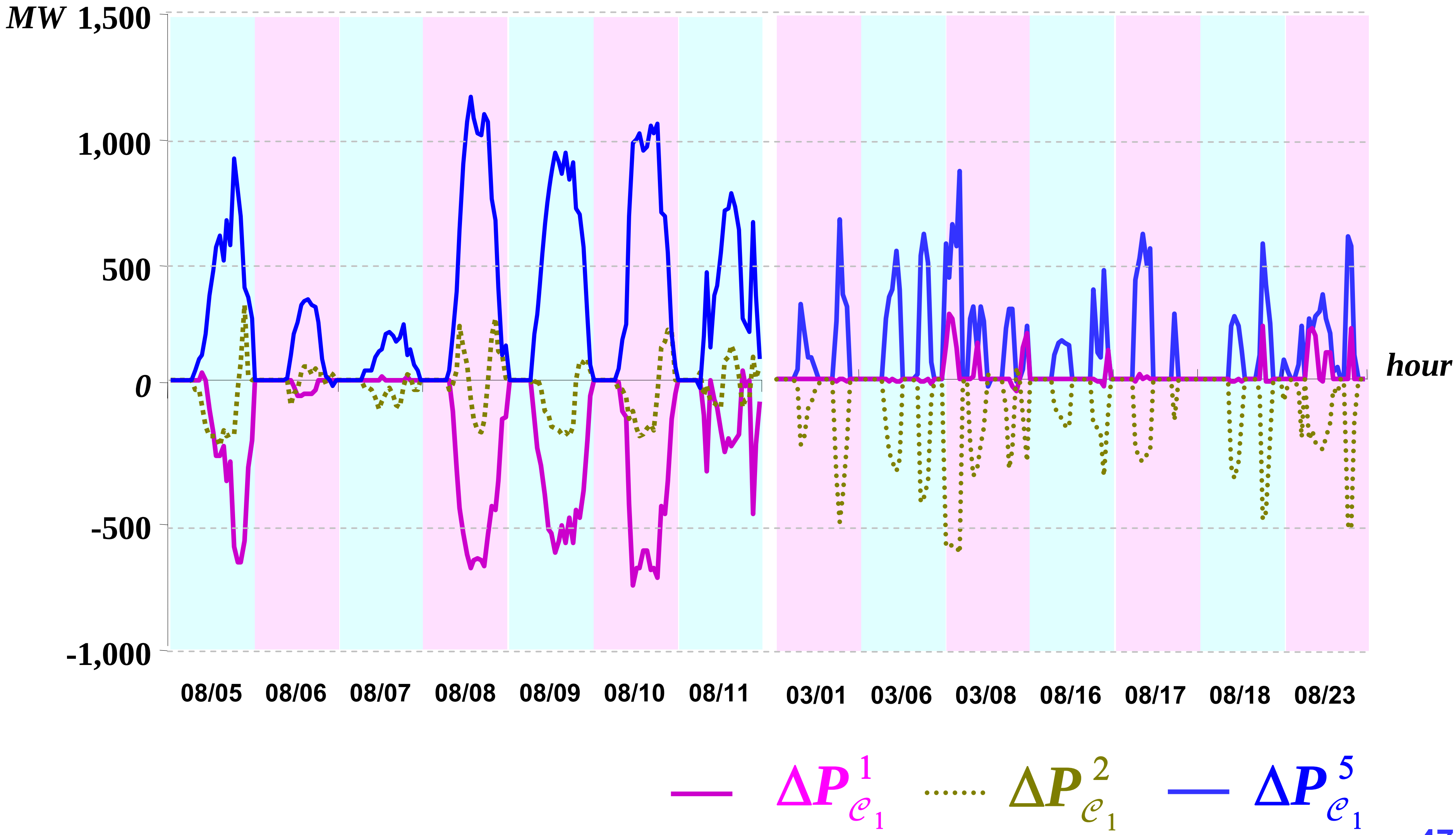
THE $\mathcal{C}_0$ CLEARED QUANTITIES



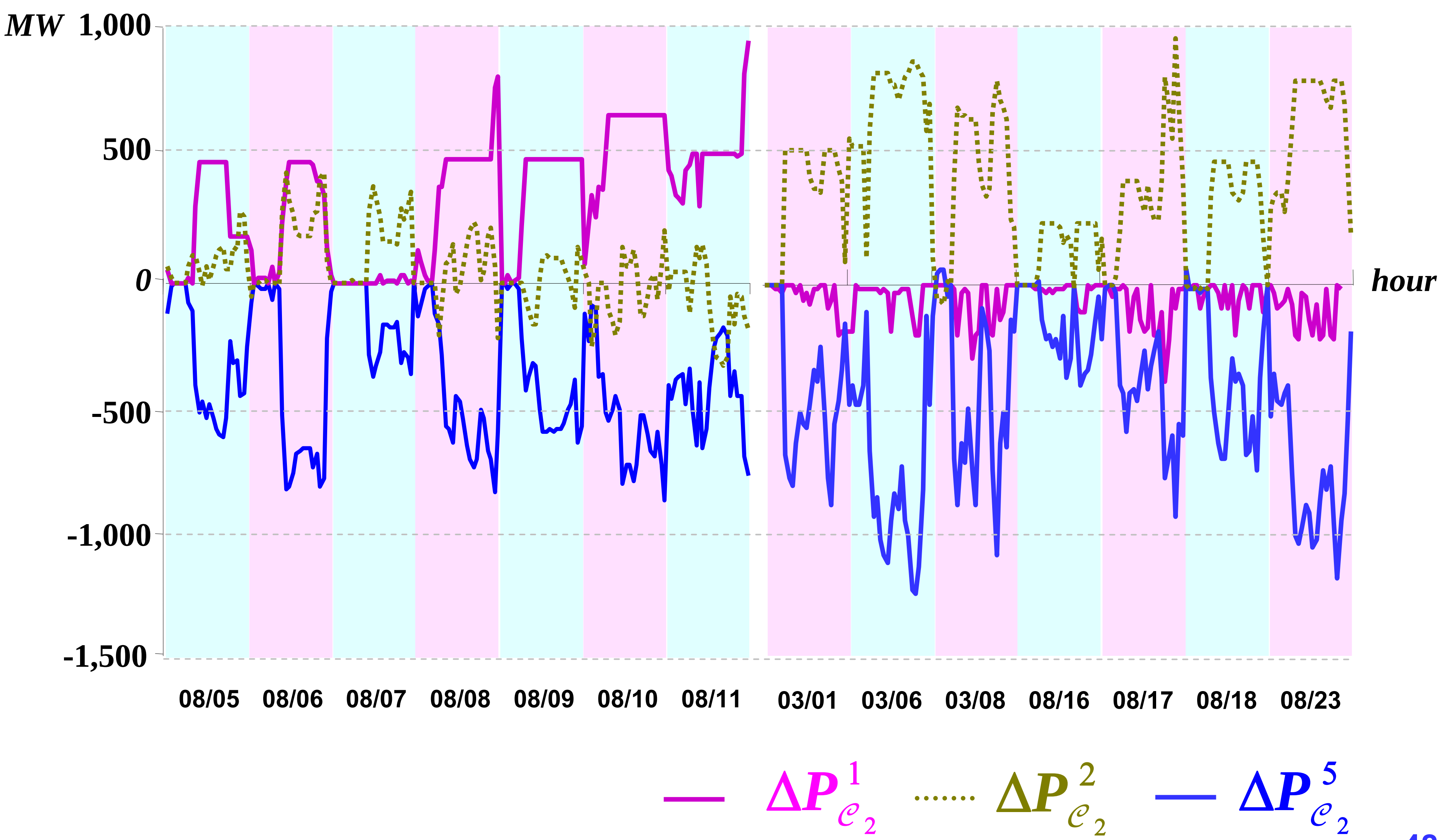
IMPACTS ON CLEARED QUANTITIES



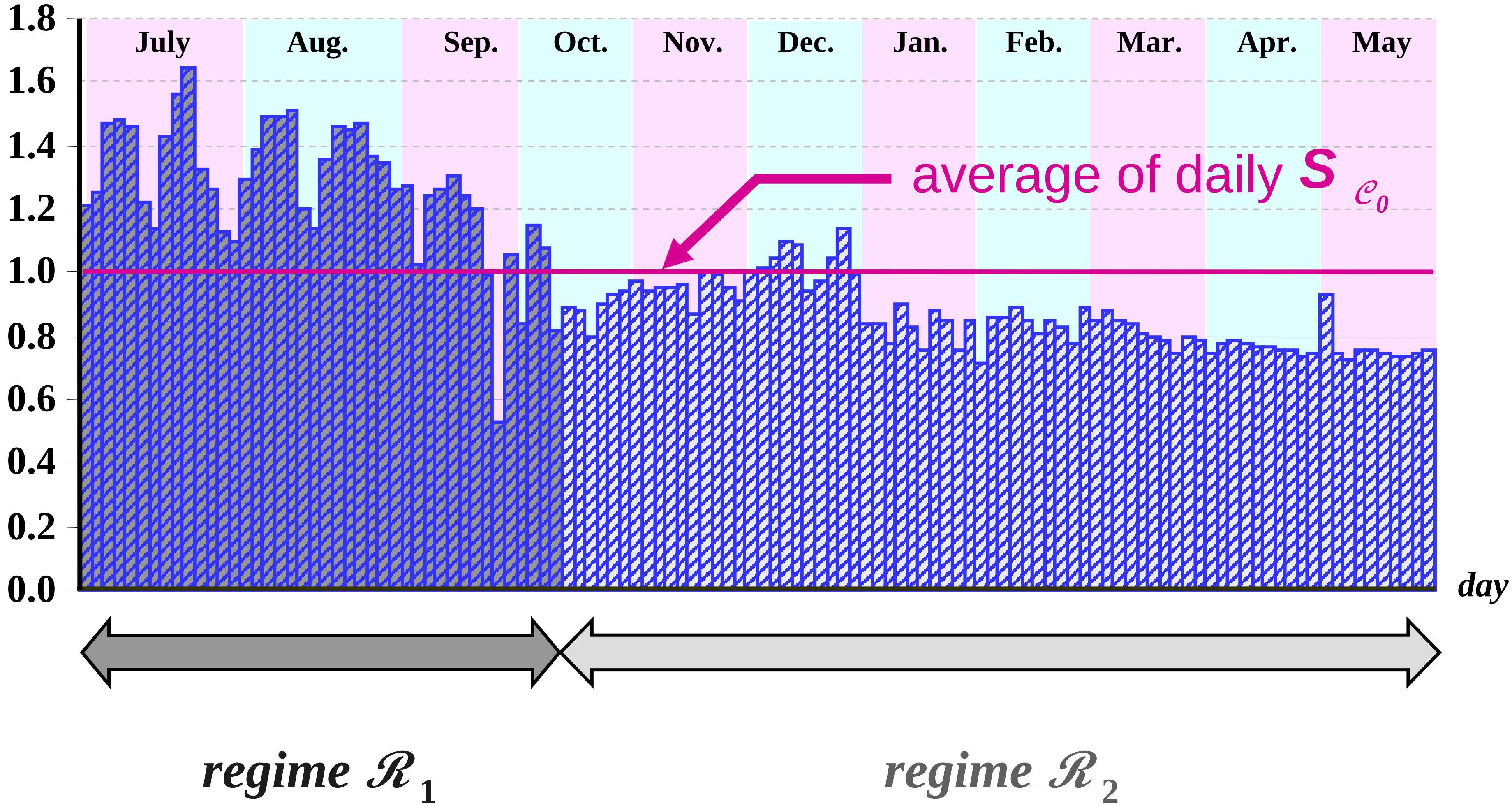
AREA – WIDE NET INJECTION IMPACTS: $\mathcal{C}_1$ wrt. $\mathcal{C}_0$



AREA – WIDE NET INJECTION IMPACTS: $\mathcal{C}_2$ wrt. $\mathcal{C}_0$

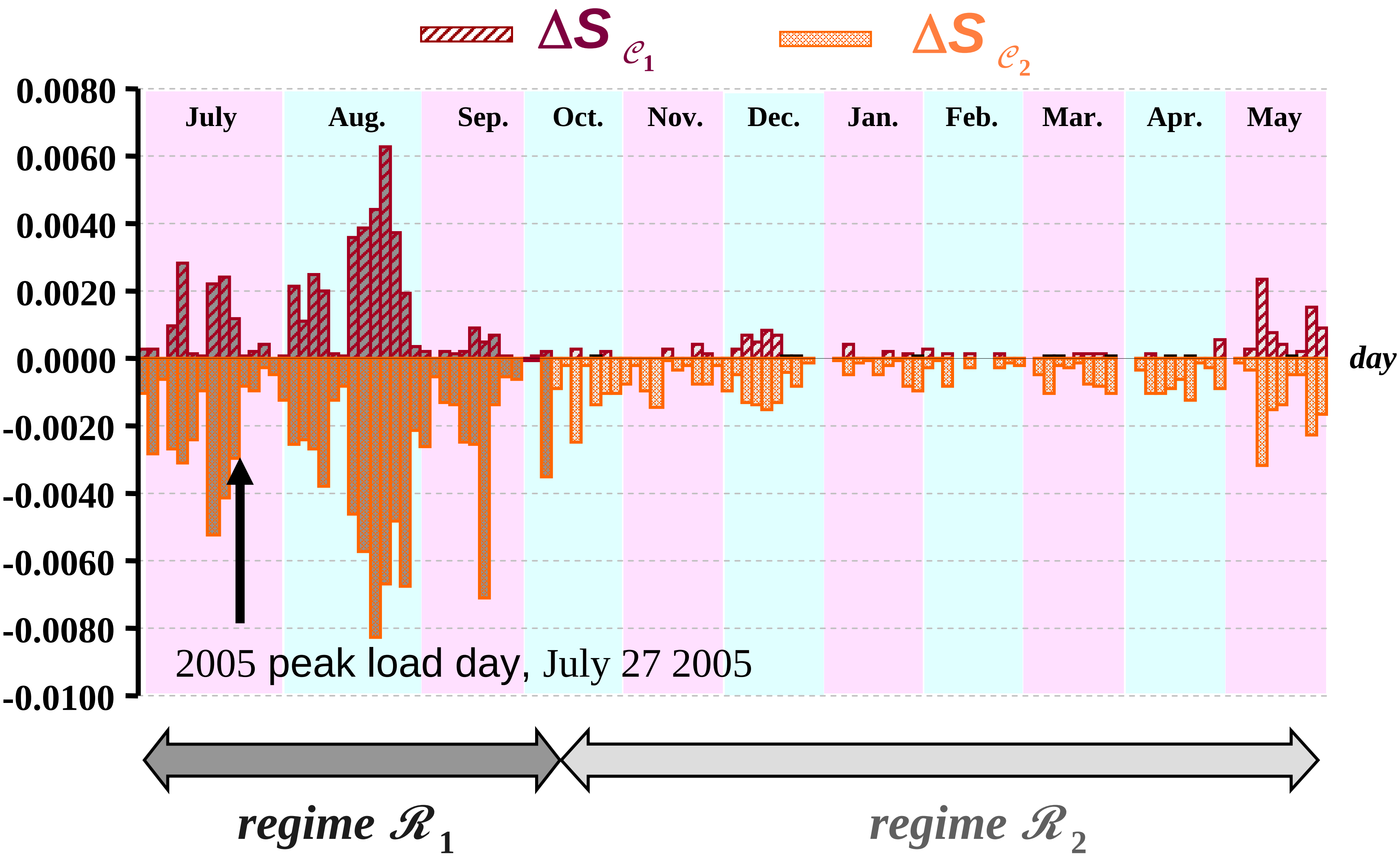


DAILY SOCIAL WELFARE UNDER THE CRITERION $\mathscr{C}_0$



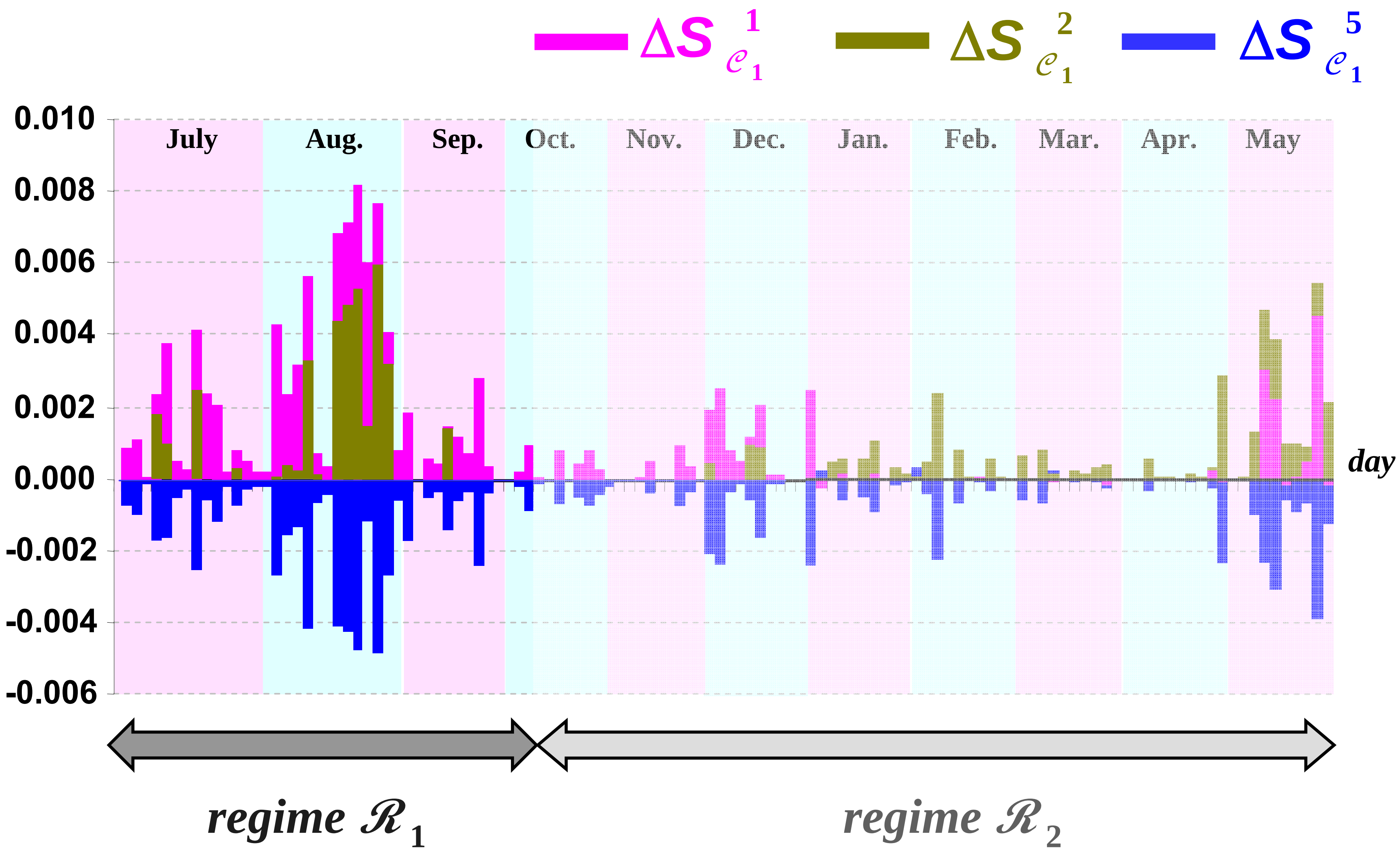
the results are normalized by the average social welfare under reference criterion $\mathscr{C}_0$

DAILY MARKET EFFICIENCY IMPACTS



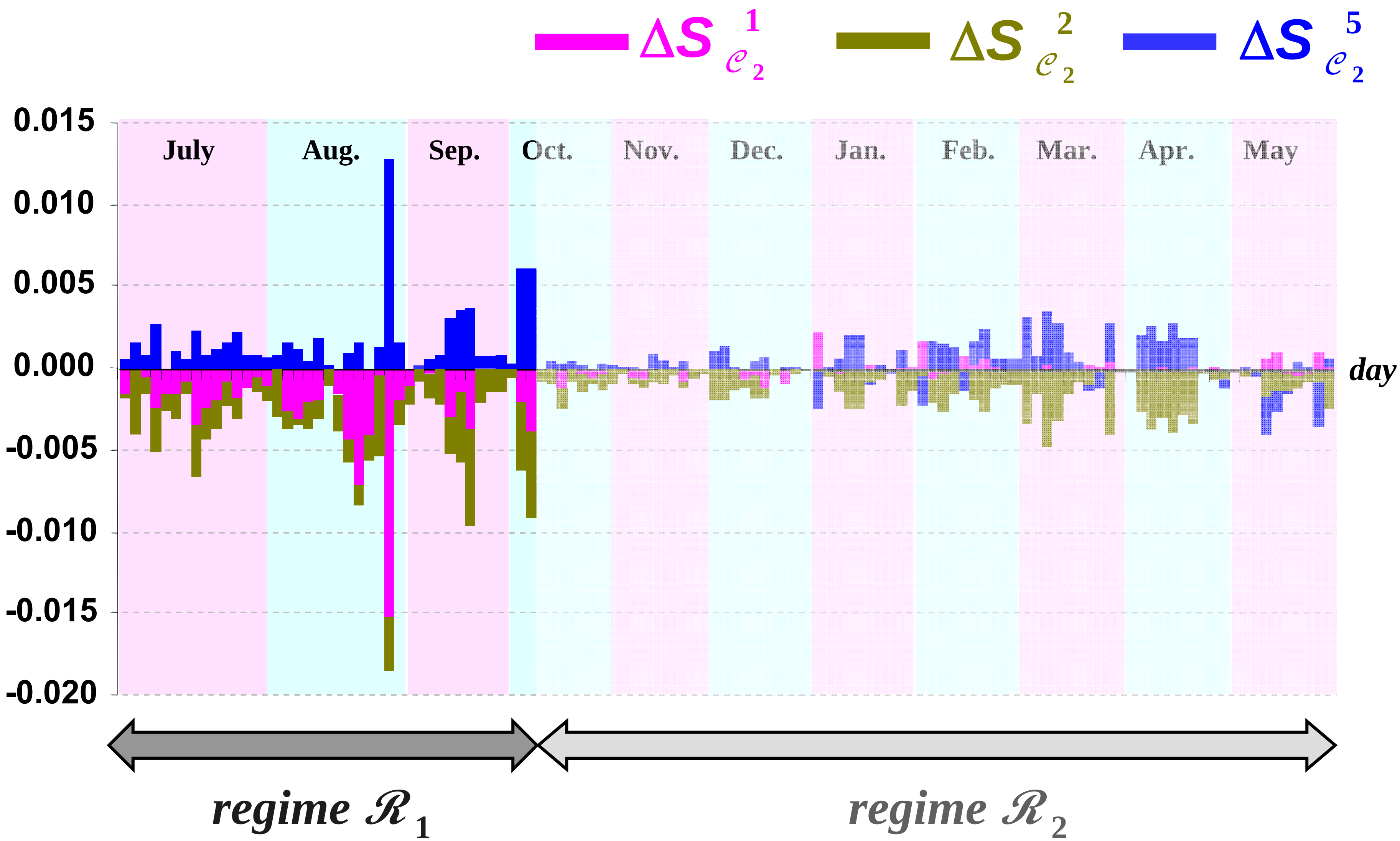
the results are normalized by the average social welfare under reference criterion $\mathscr{C}_0$

CHANGES IN THE AREAS' S CONTRIBUTIONS: $\mathcal{C}_1$ wrt. $\mathcal{C}_0$



the results are normalized by the average social welfare under reference criterion $\mathcal{C}_0$

CHANGES IN THE AREAS' *S* CONTRIBUTIONS: $\mathcal{C}_2$ wrt. $\mathcal{C}_0$



the results are normalized by the average social welfare under reference criterion $\mathcal{C}_0$

REMARKS

- The increased import capabilities arising from the relaxation of the security criterion from $\mathcal{C}_0$ to $\mathcal{C}_1$ are utilized leading to higher market efficiencies
- On the other hand, the decreased import capabilities due to security criterion change from $\mathcal{C}_0$ to $\mathcal{C}_2$ may lower the market efficiencies

REMARKS

- The price responsive regime $\mathscr{R}_2$ leads to a strong attenuation of the economic impacts of changing security criterion to either $\mathscr{C}_1$ or $\mathscr{C}_2$
- The economic efficiency of the electricity markets need not decrease when a power system is operated under a stricter criterion as long as there is effective price − responsive demand and appropriate control actions are deployed

POSSIBLE APPLICATIONS OF THE PROPOSED APPROACH

- Justification by the RTO of the decision to modify the security criterion to be used
- Costs/benefits analysis of network improvements to mitigate the market performance impacts of a set of specified contingencies
- Formulation of the control actions for specific contingencies

SUMMARY

- We develop a general approach to quantify the monetary impacts of complying with a specified security criterion
- We illustrate an application of the proposed approach on the ISO−NE *DAM*
- Our investigation provides important insights into the role of price responsive demand and that of the security control actions