Impact of Renewable Energy Availability on Load Serving Entity's Sale Price and Procurement Decisions

Paper ID - 117

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Introduction

- Retail Electricity Market – Second stage of trading take place
- Load serving entity (Retailer and Distribution Company) and consumers (End user) take part

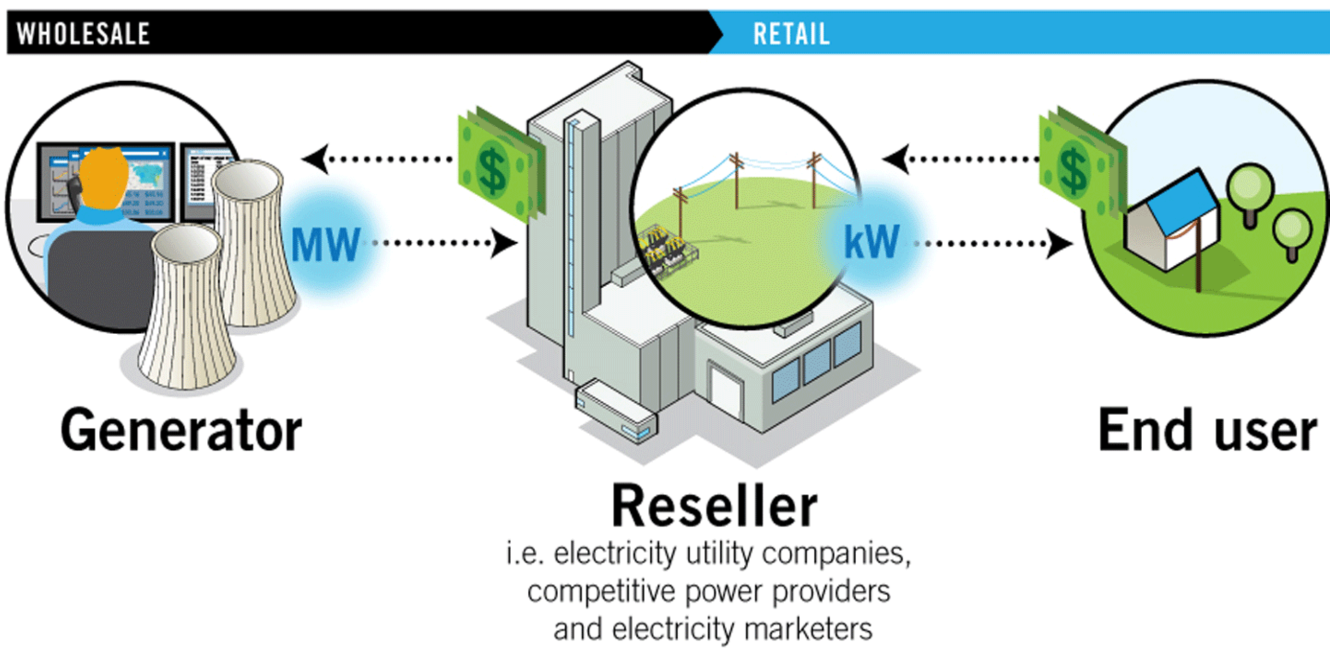
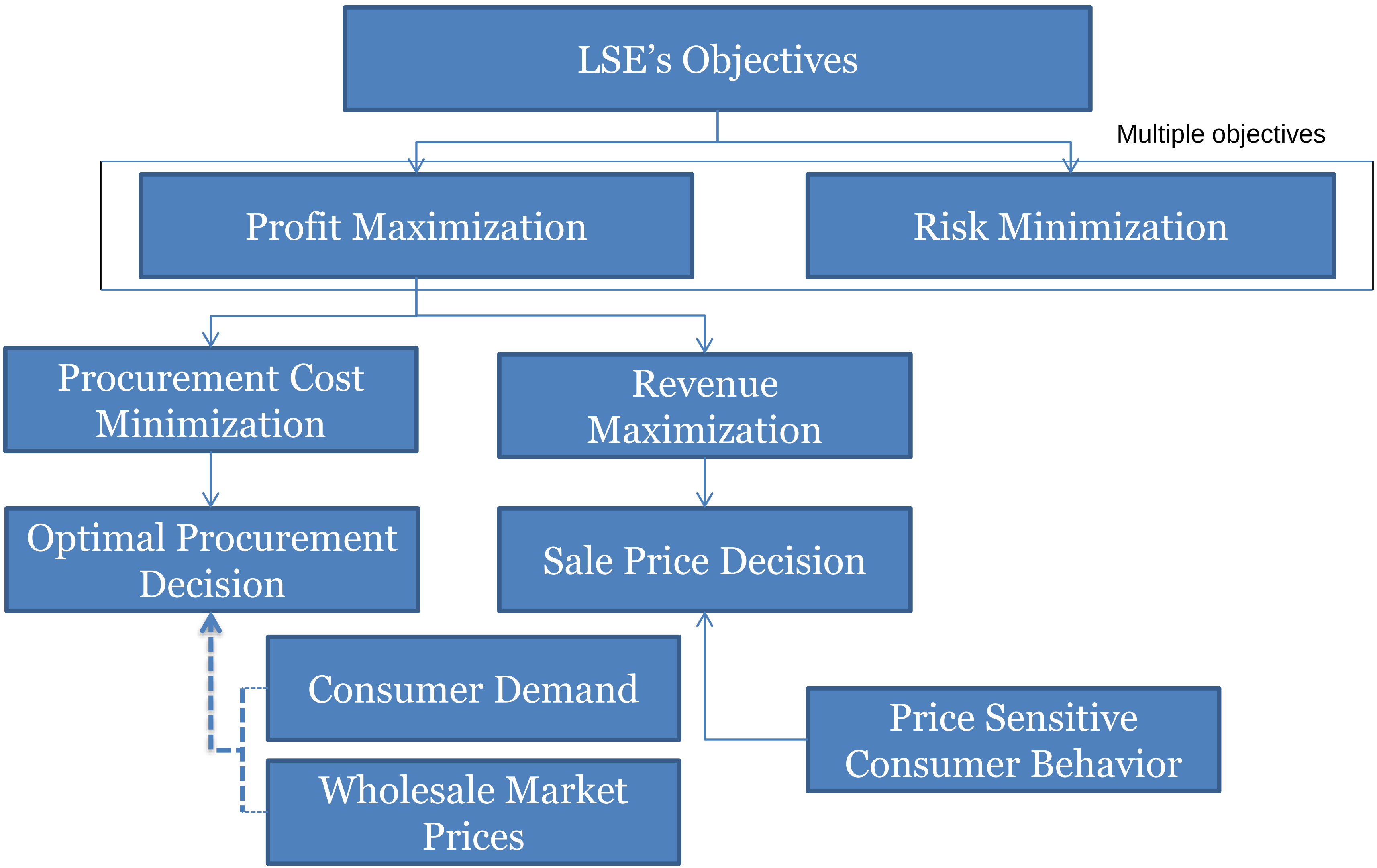


Fig. 1. Electricity Market

* Source - https://learn.pjm.com

LSE's Decision-Making Problem



Procurement Side

- Wholesale electricity market (WEM) - Prices are volatile
- Bilateral contracts- Fixed price fixed power contract
- Self-generation facility
  - Thermal generating unit
  - Renewable sources: Solar and Wind

Uncertainty Involved

- Wholesale electricity market (WEM) price uncertainty
- Renewable Uncertainty

Sale Side

- LSE can offers electricity under
- Fixed Pricing
  - Price is kept fixed for several months
  - Do not reflect actual wholesale electricity prices
  - Consumers are not exposed to wholesale price volatility
  - Example - Flat Rate
- Dynamic or Time-varying Pricing
  - Price changes over the period of time
  - Significantly reflect actual wholesale prices.
  - Consumers has exposure to wholesale price uncertainty
  - Example - Time of Use Price, and Real Time Price

Problem

- LSE's Decision-making problem in the presence of RE sources
    - Determine optimal procurement decisions
    - Determine dynamic prices
- Procurement sources
    - WEM
    - Bilateral contracts
    - Thermal Generation
    - Renewable generation: Solar and wind
- Consumer behavior
    - Price sensitivity is considered through price elasticity
- Uncertainty
    - WEM – mean variance criterion
    - RE – aggregated form

Mathematical Model

Objective Function	$Max\ Obj = \sum_t Prof_t - \beta \sum_t var_t^{WEM}$	(1)
Profit	$Prof_t = R_t - C_t^{tot}$	(2)
Cost	$C_t^{tot} = C_t^B + C_t^{SG} + C_t^{WEM}$	(3)
Revenue	$R_t = D_t^{act} \lambda_t^{sale}$	(4)
Demand function	$D_t^{act} = D_t (1 + \varepsilon_t \frac{\lambda_t^{sale} - \lambda_t^{nsale}}{\lambda_t^{nsale}})$	(5)
Variance (Risk)	$var_t^{WEM} = (P_t^{WEM})^2 . var(\lambda_t^{WEM})$	(6)
Demand shifting	$\sum_t D_t^{act} = \sum_t D_t$	(7)

Constraints

LSE's Objective function is subjected to following constraints

- **Bilateral contracts constraints**
  - Limits on minimum and maximum purchase
- **Wholesale electricity market constraints**
  - LSE can procure from WSE
- **Thermal-generating unit constraints**
  - Start up and shut down cost limits
  - Ramping up and ramping down limits
  - Minimum up time and down time limits
  - Minimum and maximum generation limits
- **Sale price constraints**
  - Upper and lower bound on sale prices
- **Energy balance constraint**

Renewable Generation

RE Sources: PV and Wind based self-generation

Procurement cost: Total cost from PV and wind is

$$C_t^{RE} = P_t^{PV} \lambda_t^{PV} + P_t^{W} \lambda_t^{W}$$

RE Uncertainty Consideration:

Energy from RE sources are considered in aggregated form

Case Study

- The proposed model is illustrated via a case study of a LSE in PJM market.
- Planning period - 24 hours of a day
- One bilateral contract is considered for 24 hours of a day
  - Price - 34$/MWh.
  - Minimum power procurement limit - 30 MW
  - Maximum power procurement limit - 350 MW
- A thermal self-generation unit - 130 MW
- Consumers elastic behavior in response to LES's selling price with hourly varying rate is considered equal to -0.4.
- RE Price - 28$/MWh
- Flat rate - 35 $/MWh
- Nominal sale price = Flat rate
- Min. and max. variation on sale price=18% of flat rate

Considered Cases

Case-1: PV: 15% of total LSE's demand.
Case-2: PV: 20% of total LSE's demand.

Case-3: Wind: 15% of total LSE's demand.
Case-4: Wind: 20% of total LSE's demand.

Case-5: PV and Wind: 15% from PV and 15% from Wind
Case-6: PV and Wind: 20% from PV and 20% from wind.

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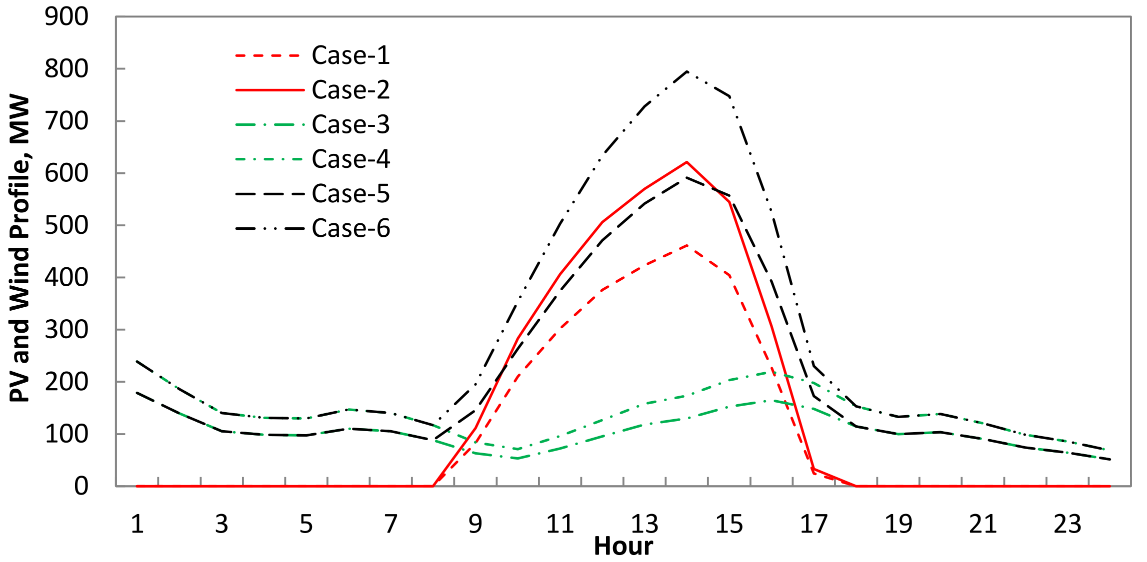


Fig. 1. PV and Wind profile for different cases

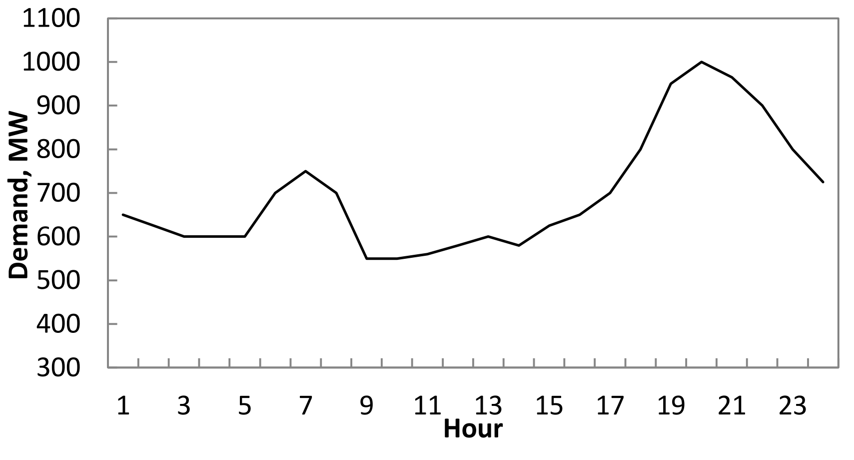


Fig. 2. Demand Profile.

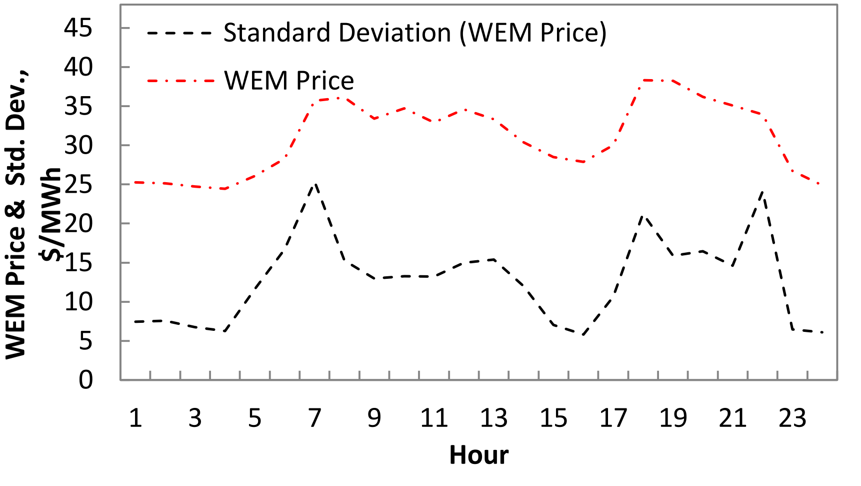
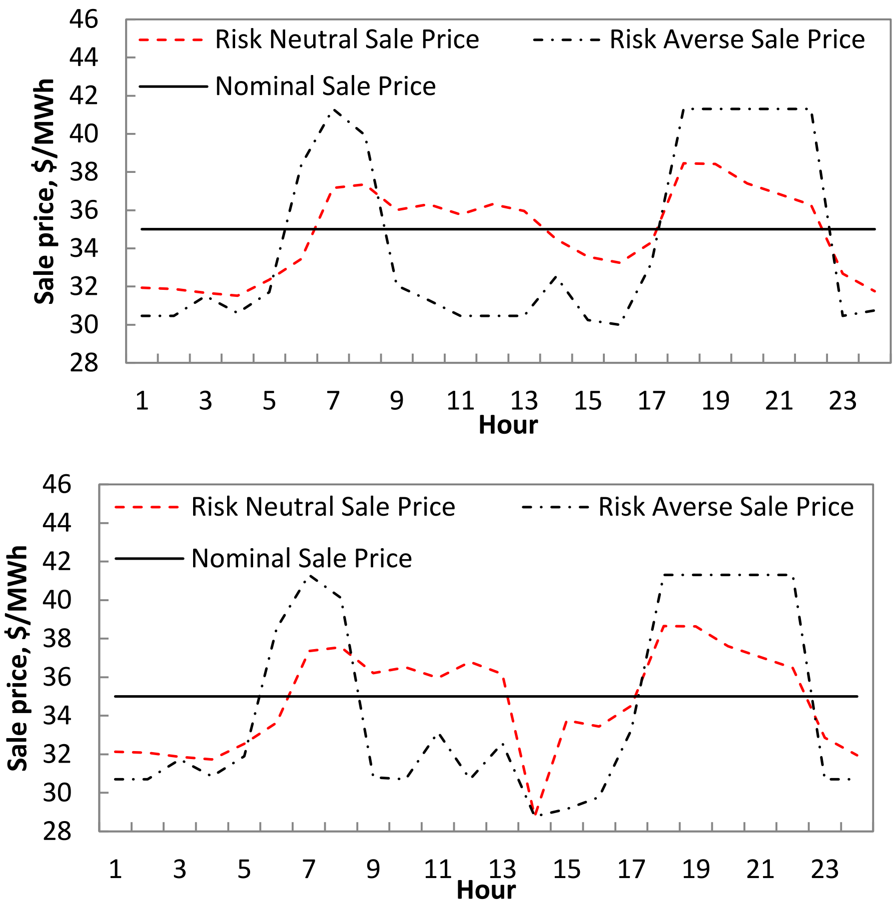
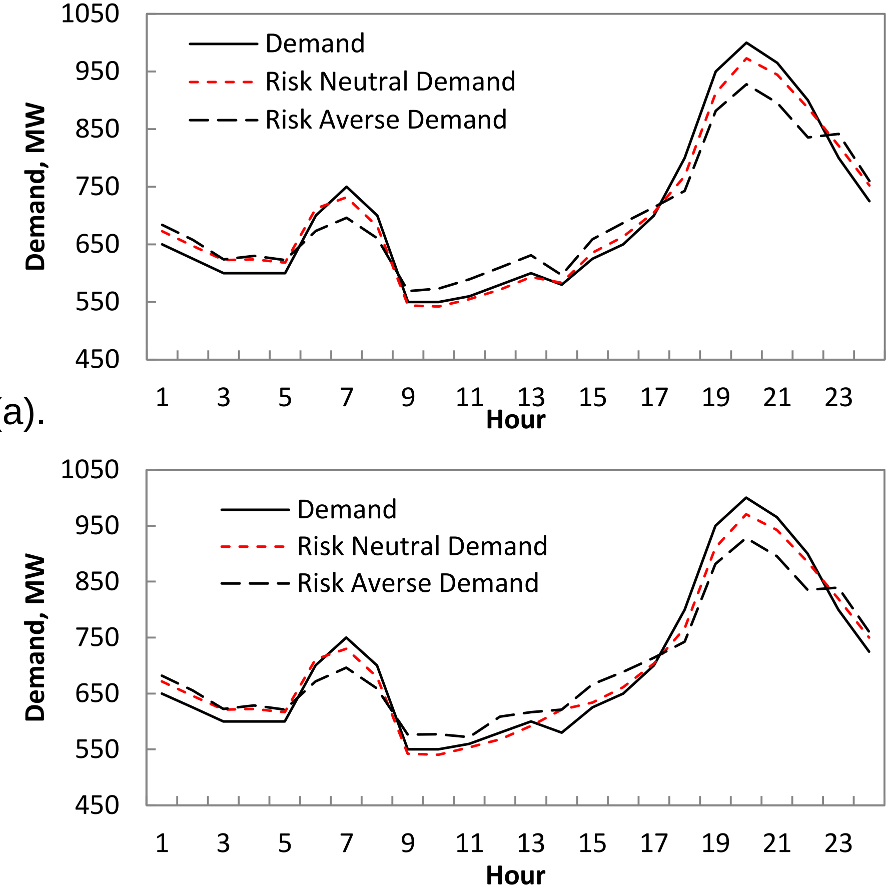


Fig. 3. WEM prices, and standard deviation of WEM Prices.

Simulation Results for Case-1 and 2 (with PV)





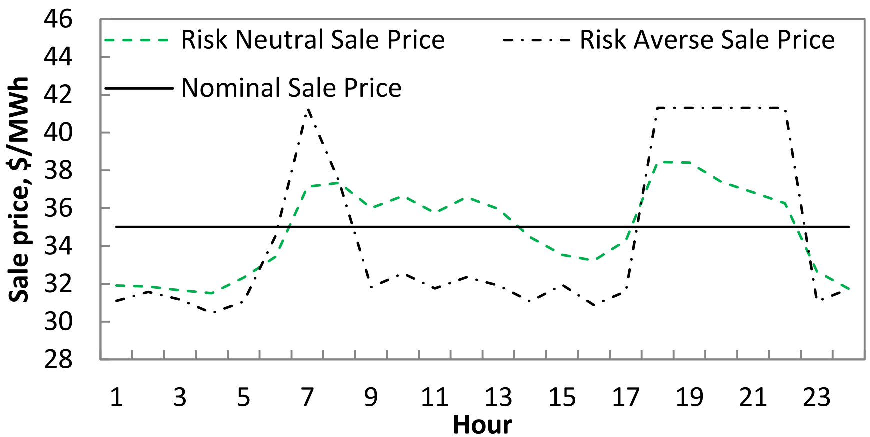
(a).

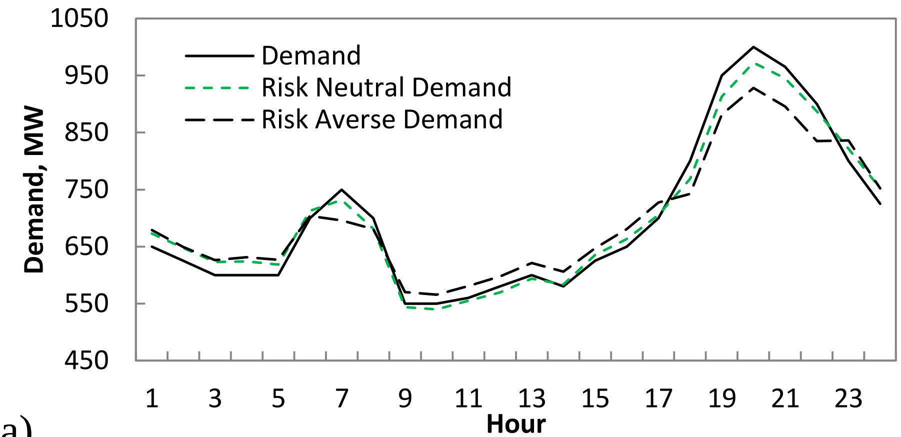
(b).

Fig. 4. Dynamic sale prices for (a). Case-1 and (b) Case-2.

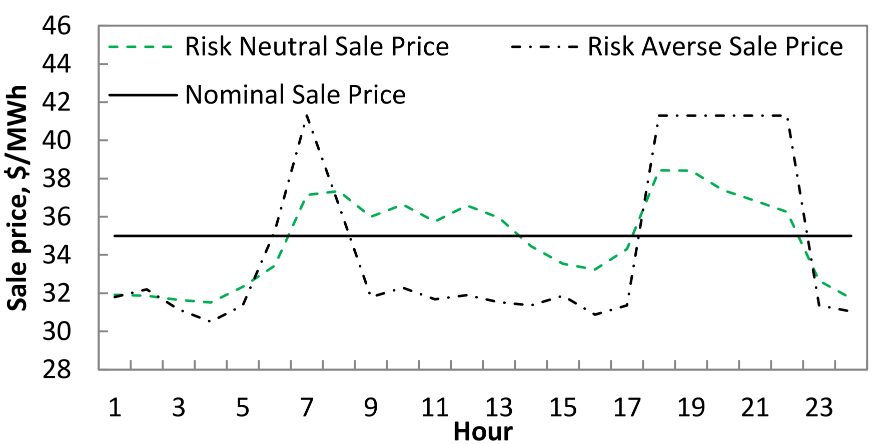
Fig. 5. LSE demand for (a). Case-1 and (b) Case-2.

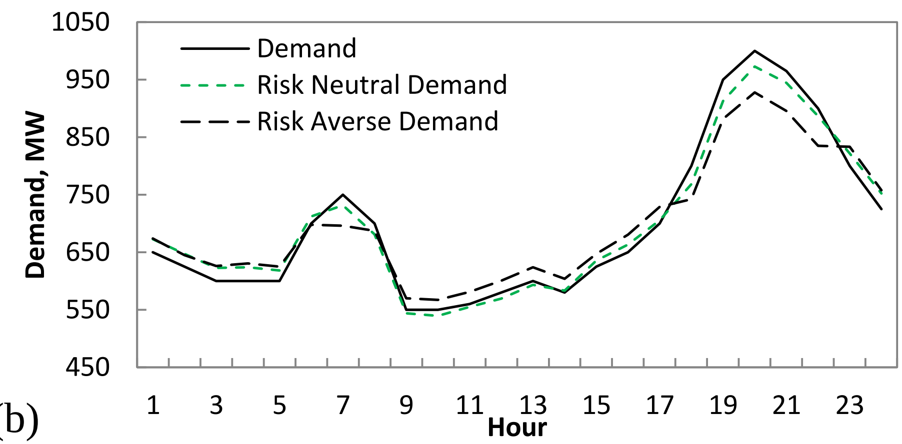
Simulation Results for Case-3 and 4 (with Wind)





(a)



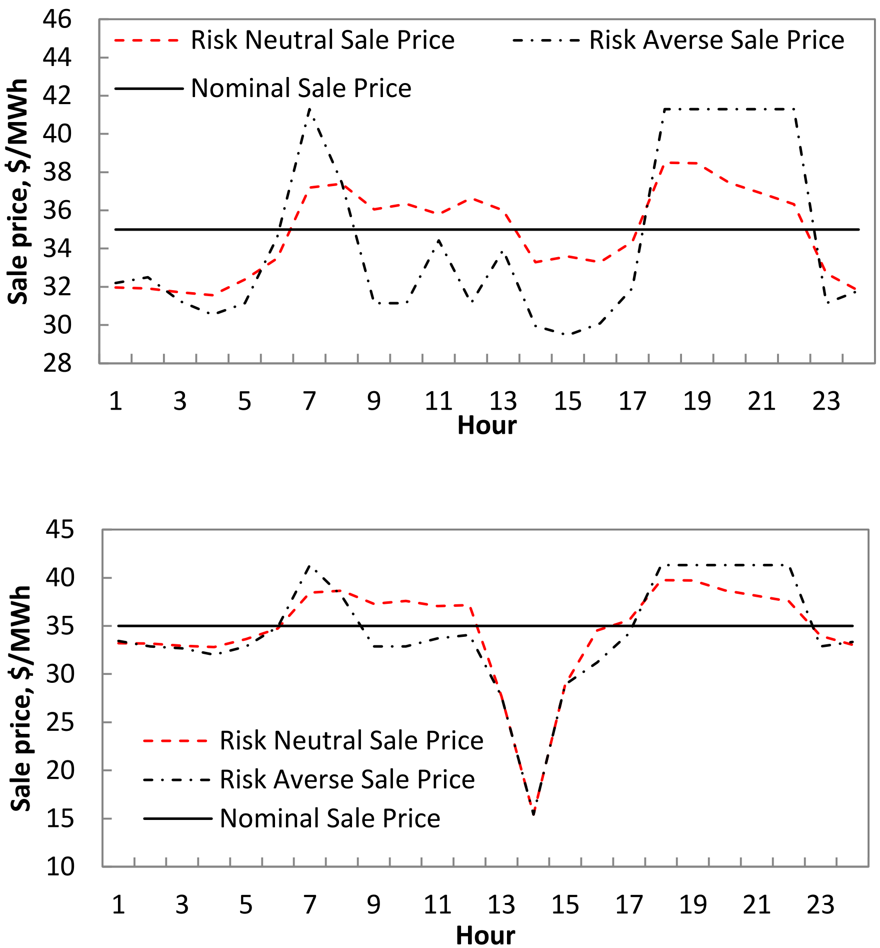


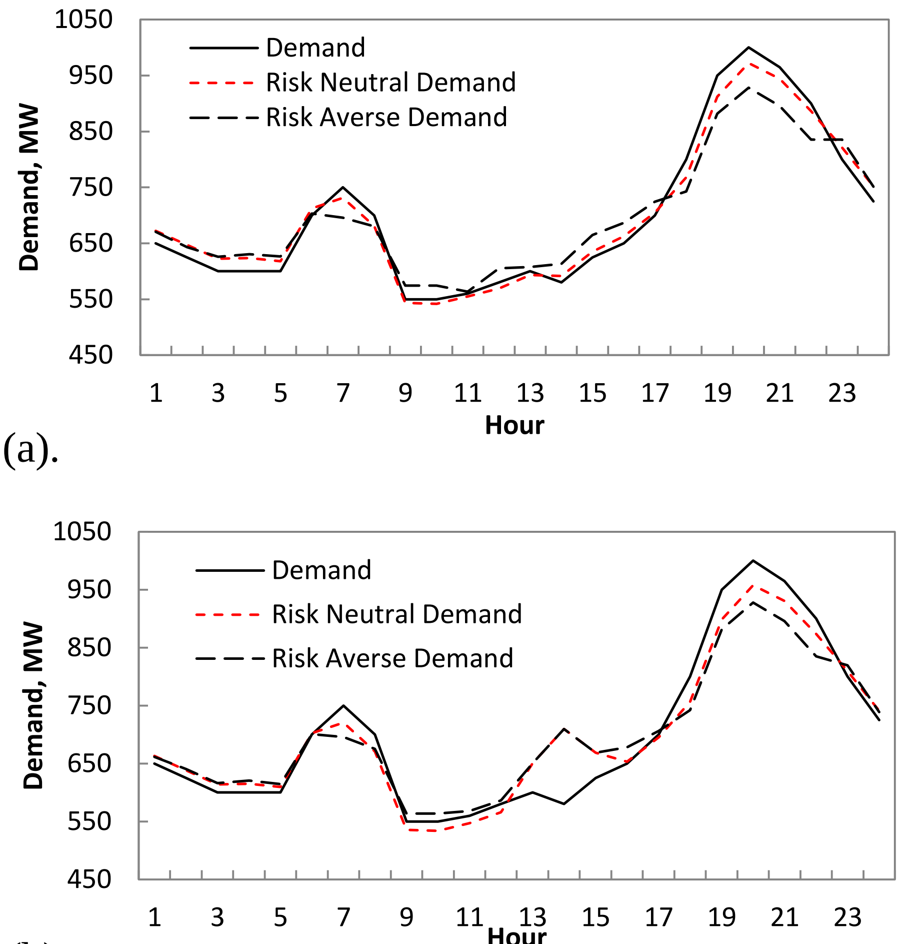
(b)

Fig. 6.Dynamic sale prices for (a). Case-3 and (b) Case-4

Fig. 7. LSE demand for (a). Case-3 and (b) Case-4.

Simulation Results for Case-5 and 6 (with PV+Wind)





(a).

(b)

Fig. 8. Dynamic sale prices for (a). Case-5 and (b) Case-6.

Fig. 9. LSE demand for (a). Case-5 and (b) Case-6

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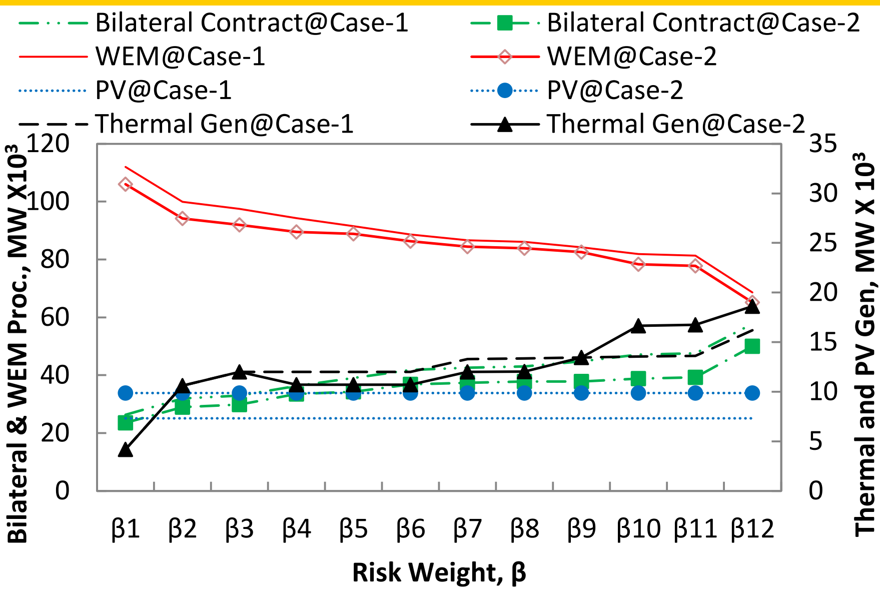
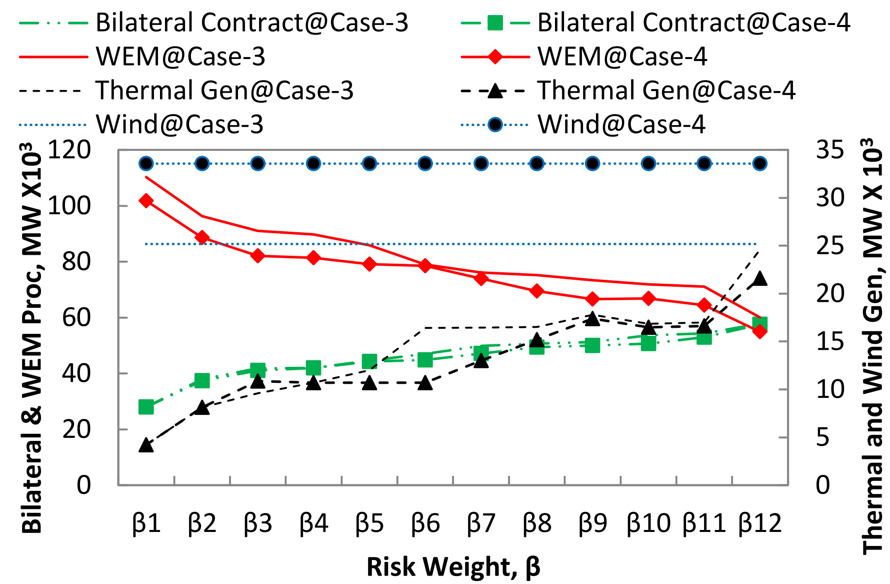
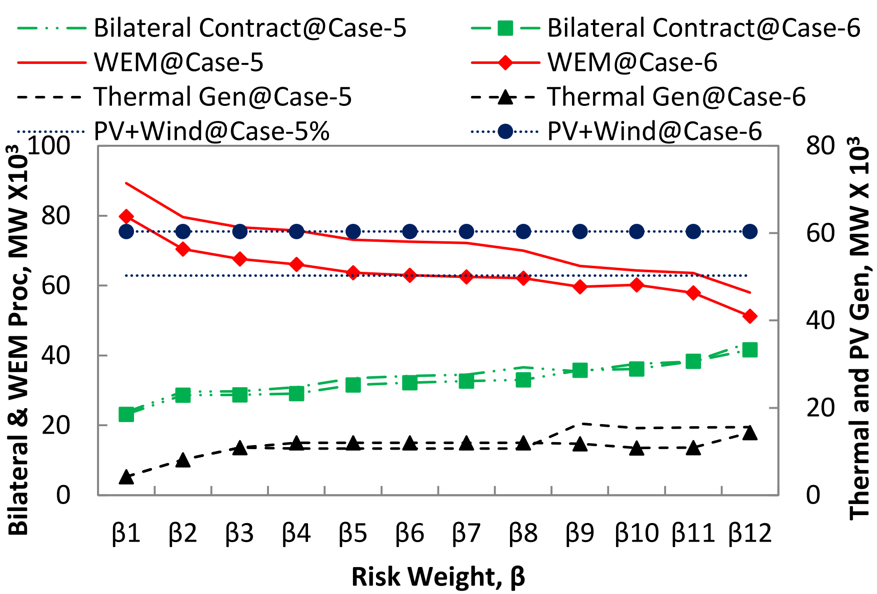


(a).



(b).



(c)

Fig. 10. Procurement from various sources for
(a). Case 1 and 2 (PV)
(b). Case 3 and 4 (Wind) and
(c). Case 5 and 6.

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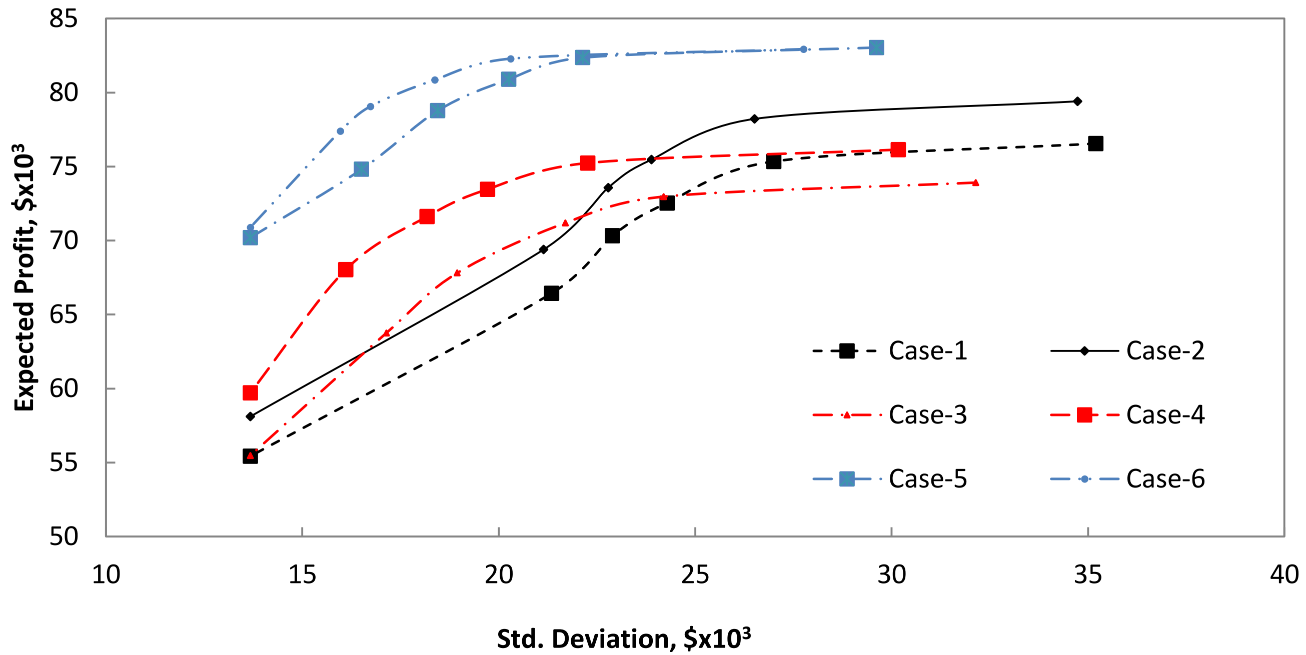

Fig. 11. Efficient frontier for case-1 to case-6.

Conclusion

- This paper proposed a decision-making model for setting dynamic sale prices and determination of LSE's modified demand for optimal energy procurement.
- Impact of RE availability from PV and Wind are analyzed individually and simultaneously.
- Results show that LSE's offers lower prices during RE availability periods.
- High RE procurement leads to further decreases sale prices to increase demand by shifting from other hours.
- LSE's expected profit decreases with risk weight, i.e. with risk-averse behavior.
- Considering the risk averse nature of an LSE, this work highlighted the impact of demand behavior on LSE's decision-making.

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