Computer Science and Future Energy Systems

Han La Poutré
CWI, Amsterdam
Centrum Wiskunde & Informatica
& Utrecht University

Contents

• Future energy systems and scenarios
• Some important ICT problem areas in SES
• Game theory and agents
• Negotiations and auctions
Current Energy Systems

• Current Energy Systems
  • Fossil ("gray") energy
  • Generators and consumers
    • Some large, central power plants
    • Large consumers (companies)
    • Many small consumers
  • Top-down approach
    • Demand prediction
    • Generation planning
    • One-way system
    • “Supply follows demand”

Future Energy Systems

• Future Energy Systems
  • Sustainable ("green") energy
  • New devices and technology
  • Massive amounts of (small) generators and devices
    • Generators
      – Solar cells
      – Wind turbines
      – Biomass
      – μCHP
    • Consumers
      – Electric cars
      – Heat pumps
Future Energy Systems

• Challenges in matching supply and demand of energy
  • Uncertain energy generation
  • Intensive energy usage by new devices
  • “Demand follows supply”

• Uncertainty
  – Uncertainty in daily operations
    • Power generation, intensive demand
  – Future scenarios: what will happen?

Future Energy Systems

• Organisation of our energy system into new, smart energy systems (SES)
  – Energy systems with ICT
  – In order to allow for durable energy generation and consumption

• “Smart Grid”
  – Electricity network that allows for sustainable power sources
  – Typically characterized by incorporation of ICT

• Challenges for deploying new devices, technology, and services
  • Technological challenges
  • Business opportunities

• Challenges for ICT
  – Next to Electrical Engineering (EE), control theory, economics, social sciences, ..
Future Scenarios:
Smart Energy Systems (SES)

- Uncertain developments for SES
  - Techniques to be developed
    - Smart grids, smart homes, hardware, software, ...
  - Social issues
    - User acceptance, energy awareness, ..
  - Economic issues
    - Business models, return on investment, ..
  - Governance
    - Laws, regulations, standards, ..

- A challenge: possible future scenarios for SES
  - How will SES evolve in the future
    - Interconnected aspects
  - What are the possibilities, constraints, and characterization

- How to develop the right technology
  - ICT, electric hardware, etc.
Impact on SES 2020

Figure 1: Driver Analysis: Driving Forces influencing the Design of Future Smart Energy Systems. Result of the Munich Workshop in May 2011 on User Experience and Future Scenario Research on Smart Energy Systems [CDTM/ICT Labs]

Strategic Scenario Drivers SES

- **Environment**
  - resources, nature, infrastructure, pollution, etc.
- **Economy**
  - rules, markets, competition, changes, etc.
  - business models, return on investment, ..
- **Politics**
  - laws, rules, regulations, structures, standards, etc.
- **Individuals**
  - behavior, goals, motivation, (energy) awareness, acceptance, etc.
- **Society**
  - values, behavior, relations, ways of life, social aspects, etc.
- **Science & Technology**
  - devices, services, smart grids, smart homes, hardware, software, ...
- **How to develop** the right technology, esp. ICT
  - ICT, electric hardware, etc.
Some Important ICT Problems in SES: supply/demand matching

- **Management and control systems** for electricity (distribution) networks
  - Many actors
    - Large generators, prosumers, farms, e-vehicles, large prosumers
  - Uncertainty
    - Uncertain sustainable generation
    - Intensive demand
  - How will demand follow supply?
    - Novel...; demand side management
  - Dynamic supply/demand matching
    - How to achieve this?

- **Smart grids**: Electricity (distribution) networks, with
  - Smart control of supply and demand
  - Smart sensing of network states; data processing
  - Smart consumers and producers connected to the grid

**Optimization/Control Objectives**

[Diagram showing various factors affecting total cost, such as losses, CO2 emissions, efficiency of powerplants, following bought profile, APX, cable aging, and maximise de-central production volume.]
ICT Techniques for
Supply/Demand Matching

• Some (first) approaches and solutions exist
  – E.g., first market mechanisms (Powermatcher,..), first clustering techniques (microgrids,..), smart power management (factories,..), ...

• A variety of settings exist
  – Depending on areas, possible business roles, regulation, etc.
  – Different solutions needed (as above)

• And:
  – We want (to keep our) stable electricity supply!
  – Current power system: 99,99% reliability.

ICT Techniques for
Supply/Demand Matching

• Coordination and control
  – Remote control
    • At homes, by electricity companies
      – Electric devices (freezer, e-vehicle, heater, μCHP)
      – Optimization techniques
      – Data about (all) consumption desires
  – Actors respond via market mechanisms
    • Dynamic pricing
    • Auctions (several types)
    • Other market types
      – Negotiation
  – Other forms of organisation
    • Contracting (day/night, advanced, …)
    • Clustering (smart neighbourhoods)
  – Agent systems
    • Various forms
 ICT Techniques for Supply/Demand Matching

• **Questions in Computer science: tackling high complexity**
  - Large amounts of data and decisions (computations)
    - Millions of households in NL; smart meters in network
    - Tbytes data per day; millions of decisions per day
    - Aim for decentralized ICT solutions
  - Efficient ICT solutions
    - Efficient (market/coordination) mechanisms for supply/demand matching
    - Fast response and computation
  - Stable ICT solutions
    - Low uncertainty (of market prices): predictability
  - Scaleable ICT solutions
    - For hundreds to thousands to millions of actors
  - Robust solutions
    - Heterogeneous environments: large and small actors, ..
    - Reliability of ICT performance
    - Keep the 99,99 % reliability...

  – Typical Computer Science issues

 ICT Techniques for Supply/Demand Matching

• **Questions in Computer science: tackling high complexity**
  - E.g.: Efficient solutions
    - Can the ICT system react fast on sudden changes
    - Can I indeed get all my desired power when I want? What if not?
  - E.g.: Stable solutions
    - How do I know that using my washing machine this afternoon, with sunny weather, indeed gives low prices?
    - How do I know that when the washing/drying machine starts, prices remain low for the next hours? Any guarantee?
  - E.g.: Robust solutions
    - Will prices remain low when just one large consumer suddenly may start using power?
    - What happens if everybody uses the same software with similar decisions?

  – (Market) mechanisms that yield sufficient certainty?
Some Important ICT Problems in SES

• Local scheduling and planning
  – Consumers become prosumers
    • Consumers also generate energy at e.g. homes
    • Solar cells, CHPs, wind turbine, ..
    • E-vehicles
  – How to optimize their comfort
    • When to generate/store/consume/deliver power?
    • Usage at homes; flexible
    • According to the user’s preferences
  – Sensing, scheduling and optimization techniques
    • User preferences for optimization
    • Sensor networks for learning user behaviour
    • Price forecasting
    • Optimization algorithms
    • VPPs (Virtual Power Plants)

Smart Energy Systems - Conclusion

• Smart Energy Systems
  – Novel ICT required
  – Requirements from
    • EE, society, regulations, economy, business
  – Several basic solutions exist
  – More advanced solutions underway
    • Computer science
      – Scalability, stability, heterogenous, ..
    • Algorithms, learning, data mining, data base systems, agents, operations research, simulation, security, privacy, control, markets, ....
Agents

• Bargaining games
  – “Games” as in game theory: formalized interaction
  – Negotiations, auctions, market mechanisms, ...

• Concept: software agent
  • Independent piece of software
    – Can interact autonomously with other agents
  • For automatic bargaining on behalf of a party
    – E.g., its owner
    – Competitive agent
  • Multiagent system
    – Bargaining together
  • Conceptual use
Games

- **Game**: players that interact with each other
  - And get a payoff at the end

- A game is defined by its **rules**
  - **Who** can do **What** and **When**;
  - Who **gets what** at the **end** of the game

- **Games strategy** of a player
  - Description of the actions by that player

- **Negotiation/auction**: specific type of game
  - Agents want to make a deal
  - 2 or more players: e.g. buyer and seller
  - Usually involves alternating-offers for negotiation

Mechanisms for Allocation

- Two main types of mechanisms for allocation of goods:

  - **Auctions**
    - Fixed protocol and rules, mainly centralized
    - Possible to design optimal mechanisms that guarantee certain desirable properties – especially in one-shot settings
    - Often target at direct revelation (bidders reveal the prices for preferred combinations), presence of a trusted center

  - **Negotiation (bargaining)** mechanisms:
    - Allows the use of more decentralized, flexible protocols
    - Allows customized and complex agreements
    - Agents can use incomplete information about their opponent (and their own) preferences
    - Focus is on designing agent strategies, not the mechanism itself
Utility Functions

• How to measure outcomes?

• Utility function $u(o) = \text{function } u \text{ that maps all possible game outcomes } o \text{ in the choice set into } ...$
  – a real number: Cardinal utility - (e.g. between 0 - 1)
  – an ordering between outcomes: Ordinal utility - specifies only an ordering between outcomes

• Utility functions can be:
  – Over a single issue (e.g. only over price)
  – Over multiple issues (attributes)
  • Discrete-values
    – Excellent (10), “good” (8), average (6), bad (4), ...  
  • Continuous
    – Real values (7.5 euros, 3.2 kg, 2.46 sec,...)
Example: Negotiation

- Agents negotiate about the exchange of services or goods and a price

- *(Monetary) Utility* of a possible negotiation outcome $D$ for each agent $a$ is e.g.:
  - Amount it is willing to pay for the goods/services exchanged in the deal: its valuation $v_a(D)$
    - the deal's/goods/services value to it
  - minus the price of the deal itself for it: $p_a(D)$
    - the actual price it has to pay
  - thus $v_a(D) - p_a(D)$

- Each agent wants maximal utility: “economic rationality”

Example Utility

- E.g., a possible negotiation outcome:
  - Agent 1 gives one television to agent 2
    - Agents 1’s valuation: 500 euro; agent 2: 300 euro
  - Agent 2 gives two goods to agent 1: car and a bicycle
    - Agent 1’s valuation: 2500 euro; agent 2: 1000 euro
  - Valuation of the goods transfer in the deal:
    - for agent 1 this is +2000 euro
    - for agent 2 this is -700 euro

- If in addition, agent 1 has to pay the price of 1000 euro to agent 2, then for this possible outcome:
  - the deal has a utility value of
    - 1000 euro for agent 1, and
    - 300 euro for agent 2
Pareto Efficiency

• How good is an outcome?

• Pareto efficiency (pareto optimal):
  
  – A game outcome \( d \) is pareto efficient if there is no game outcome that is better for at least one agent and not worse for the other agent(s):

  \[
  \begin{align*}
  u_A(d') &\geq u_A(d) \quad \text{and} \quad u_B(d') \geq u_B(d) \quad \text{and} \\
  u_A(d') &> u_A(d) \quad \text{or} \quad u_B(d') > u_B(d)
  \end{align*}
  \]

Evaluation Criteria
Negotiation/Auction Mechanisms

• Mechanisms: some evaluation criteria / goals
  – Pareto efficiency
  – Social welfare
  – Stability
  – Individual rationality
    – Better than fall-back option

• Design mechanism to allow/satisfy/optimize these goals
  – Possible criterion for selecting mechanisms
Evaluation Criteria

• Social welfare
  – The sum of all agents payoffs in an outcome or
  The sum of all agents utilities in an outcome
    • Try to optimize the collective ("social") outcome for the complete society/set of agents involved

• Stability
  – How stable are the outcomes of the mechanism
    • E.g. Nash equilibrium, dominant strategies, best response

Stability

• Dominant strategy for a player A
  – A best strategy that A can play, no matter what the other players do

• Best-response strategy S for player A
  – Given (!) the strategies of the other players, then S is a best strategy for A to play.

• Nash equilibrium
  – "no agent has the incentive to deviate from his strategy given the others"
    • Notion of stability and robustness of the situation
    • Equilibrium
  – A set of strategies \( (S_1, S_2, \ldots, S_k) \) for players \( A_1, A_2, \ldots, A_k \) is a Nash equilibrium (NE) if for every \( i \), strategy \( S_i \) is the best-response strategy that \( A_i \) can play given the strategies of the other agents.
Example:
Prisoner’s Dilemma Game (PD)

- Players can either Cooperate (C), or Defect (D)
- Every player is tempted to defect given the other players move

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<thead>
<tr>
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<th>C</th>
<th>D</th>
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<td>C</td>
<td>3,3</td>
<td>0,5</td>
</tr>
<tr>
<td>D</td>
<td>5,0</td>
<td>1,1</td>
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Best-Response in PD

- **Best-Response** play to current opponent policy:
The model of the opponent reveals:
  - The opponent cooperates:
    - Defection gives the higher reward
  - The opponent defects:
    - Defection is best counter move
  - So, Defect is:
    best response in both cases, and: dominant strategy

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- Best-Response leads to symmetrical Defection: (D,D) is also a Nash Equilibrium
Nash equilibrium

- Nash equilibrium (NE) in games
  - NE does not always exist
  - Multiple NEs exist
    - Which strategy to play by an agent?

Auctions

- Auction (unidirectional)
  - Auctioneer
    - Sell an item
    - Highest possible payment
  - Potential bidders
    - Buy the item
    - Lowest possible payment
  - Usually:
    - Bidding rules
    - Allocation rules
      - Who wins/gets the item
    - Payment rules
      - What does winner have to pay
    - Above rules: often very strict
      - Easy to analyze and understand
Some Types of Auctions

• Types of auctions (unidirectional)
  
  – Iterative auctions
    • Ascending bid auctions (english auction)
      – Bidders increase their bids one by one
    • Descending bid auctions (dutch auction/flower auction)
      – Clock moves downwards in price until first bidder bids
  
  – One-bid auctions (“sealed envelopes”)
    • First-price auctions
      – One bid per bidder; highest one wins and pays that price
    • Second-price auctions (vickrey auction)
      – One bid per bidder; highest one wins and pays the second highest price
  
  – Combinatorial auctions (multiple goods)
    • Vickrey-Clark-Groves (VCG) auctions, ...

Some Types of Auctions

• Types of auctions (unidirectional, one good)
  
  • Iterative auctions
    – Ascending bid auctions (english auction)
    – Descending bid auctions (dutch auction/flower auction)
  
  • One-bid auctions (“sealed envelopes”)
    – First-price auctions
    – Second-price auctions (vickrey auction)

• Behaviour of iterative and one-bid auctions:
  – Can have similar theoretical behaviour for some properties (game theory)
    • Revenue
    • Winner determination (“efficiency of outcomes”)
    • Price determination
  
  – But also differ in others
    • Stability: existence of dominant strategies
    • Speed of auction
    • Private information revelation
    • Disclosure of market values
Some Types of Auctions

- Types of auctions (bidirectional)
  - Double actions
    - Buyers and sellers make a bid
    - Bids of buyers and sellers are “matched”, allocation with prices
      - (Uniform) clearing price is calculated
      - Discriminatory prices (price per buyer/seller)
      - Can be complex: computability
  - Continuous Double Auctions (CDAs)
    - Everlasting auction
    - Bids of buyers and sellers are matched whenever possible
      - Auction continues with remaining or new buyers and sellers
      - Discriminatory prices (price per buyer/seller / time)
  - Bids can be
    - Simple (a price or a quantity)
    - Complex (a price/quantity function)

Conclusion Auctions/Negotiation

- Auctions/negotiation mechanisms for allocation of goods

- Design/choice of mechanism is important
  - Different properties
    - Revenue, equilibriums, stability, optimality criteria, efficiency, speed, computability (winners, prices, bid-strategies), communication complexity, ...
  - Choice for mechanism
    - What properties do you need?
    - Design of new ones
    - Important in the energy domain