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AI Agents for Energy Security

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Energy security is the association between national security and the availability of natural resources for energy consumption. Access to cheaper energy has become essential to the functioning of modern economies. However, the uneven distribution of energy supplies among countries has led to significant challenges. International energy relations have contributed to the globalization of the world, leading to energy security and energy vulnerability at the same time. The first article in Science Direct for energy security appeared in 1993 with authors from USA. Gradually the number of articles and their origin increases. In 2024 we observe a boom of these publications—30 (not only in Science Direct) and one planned for 2025. The recent article explores these publications and sorts them by origin and content. The content is distributed in five topics: computer technologies impact, artificial intelligence applications, environmental management and energy security, economics and policy for energy security, and emerging technologies for energy security. Since the share of AI usage is relatively small the author suggests scenarios for AI agents' application in various situations concerning environmental decisions, failures, cyber-attacks, performance, and pricing.

Keywords: energy security, computer technologies, AI applications, environmental management, economics and policy, emerging technologies, AI agents

Introduction

Energy security refers to the reliable and affordable access to energy sources. It encompasses the ability of a nation or region to secure sufficient energy supplies to meet its needs without significant disruptions. This concept includes several key aspects:

(1) Availability: Ensuring that there are adequate energy resources to meet current and future demands.

(2) Reliability: Maintaining a stable supply of energy without frequent interruptions.

(3) Affordability: Keeping energy prices at a level that is accessible to consumers and businesses.

(4) Sustainability: Utilizing energy sources that are environmentally friendly and can be maintained over the long term.

Energy security is crucial for economic stability, national security, and overall quality of life. It involves diversifying energy sources, investing in renewable energy, and developing infrastructure to support energy distribution and storage.

AI agents are advanced artificial intelligence systems that are able to complete a task or make a decision.

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Humans set the goal, and agents figure out on their own, autonomously, the best course of action. The agents can interface with external systems to take action in the world. In addition to this autonomy, agentic AI can also receive feedback and continually improve on a task.

AI agents are a more capable version of generative AI. While both technologies rely on LLMs (Large Language Models) as their underlying model, generative AI creates new content based on the patterns it learned from its training data. Agentic systems, on the other hand, are not only able to generate content but are also able to take action based on the information they gain from their environment.

Sources for energy security published in Science Direct date 1993. In recent years the most articles appear in 2024, and some are planned for 2025. The author summarizes articles from Science Direct and other sources. The articles are distributed by origin as follows: China—thirteen (13), India—four (4), Europe—four (4), Others—nine (9) (USA, UK, Turkey, Saudi Arabia, Israel, Bangladesh, Malaysia, Republic of Korea, and Nigeria). Figure 1 depicts the distribution of energy security articles by origin.

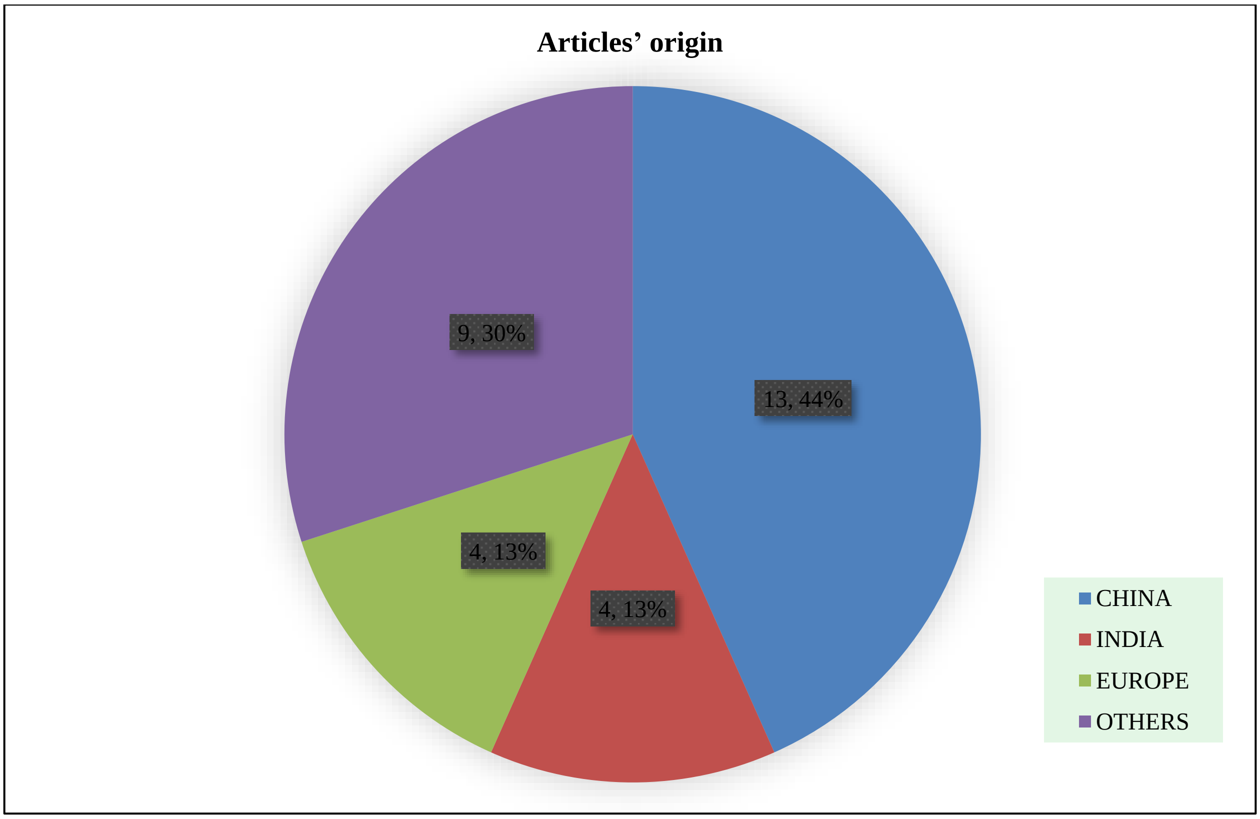

Figure 1. Distribution of energy security articles by origin.

The author classifies the articles by content in following topics:

- Computer technologies impact

Anderson (2025) makes a critical analysis of the cost, effectiveness, and sense of continuing to develop and implement highly vulnerable smart grid technology and using Internet connectivity as central control, but alternative, more secure technology and communications options should be considered. There are no details about AI agents' application in power grid and energy security. Rai, Shukla, Tightiz, and Padmanaban (2024) present IoT and Blockchain technologies for data security in nuclear energy applications. There are no details about application of deep learning for nuclear sector security. Tabassum, Islam, Azim, Rahman, Faruque, Shezan, and Hossain (2024) describe bilateral energy transactions between prosumers and IoT devices. There are no AI applications for ecological, maintenance, performance, and pricing aspects of energy trading. Alghanmi and Alkhudhayr (2024) categorize Energy Share AI as a powerful peer-to-peer energy exchange system that operates on a P2P model that integrates advanced machine learning with distributed energy sharing. The research findings indicate that blockchain technology plays a pivotal role in ensuring the security and transparency of energy transactions. Consequently, these results are an increase in user trust and engagement in the energy market. The future work includes exploring innovative business models that can drive the commercialization and scaling of these systems. Alqaisi, El-Bayeh, Alzaareer, Zellagui, Flah, and Brahmi (2024) discuss decision-making mechanism for sustainable power supply. There is no forecast for AI applications in micro-networks.

- Artificial Intelligence Applications

Zhao, Zhang, Alhazmi, Hu, Zhang, and Yan (2024) evaluate integration of Conventional Neural Networks (CNN) and Double Deep Q-Networks (Double DQN) in energy storage. Authors comment only operational security and do not consider ecological and price security. Wang, Wang, Dong, and Nepal (2024) generalize that every 1% increase in AI development will lead to a 0.032% increase in the High-quality Energy Development (HED) index. Moreover, AI indirectly increases the HED index by improving green innovation and R&D intensity. Further, the threshold effect shows that the level of digital economy development influences the impact of AI on HED. AI applications are not proposed in maintenance, safety, and pricing aspects of energy security. Van Soest, Rueda, Park, Spurling, Wyatt, Fine, Steier, and Lebret (2024) research the extent to which AI could improve energy security. Authors list only general AI-related recommendations for policymakers, regulators, and companies. Song, Wang, Song, Wang, and Liu (2024) examine AI's effect and mechanism on Renewable Energy Supply Chain Vulnerability (RESCV) and the spatial spillover in neighbouring countries. The result is positive, but there are recommendations for maintenance only of safety, stability, and reliability. Raval, Jadav, Rathod, Tanwar, Vimal, and Yamsani (2024) propose an AI-based secure data exchange framework for smart grid Critical Infrastructure, where they attempt to secure the sensor's data (i.e., power consumption, energy readings, and network data) from malicious adversaries. Future work includes exploration on: data availability and data quality, AI model complexity and overfitting, scalability, logic transparency, resilience and adaptability, AI training, and 5G communication.

- Environmental Management and energy security

Dagar, Rao, Dagher and Doytch (2024) analyse the energy trilemma: energy security, environmental sustainability, and energy equity. The future work includes exploration of causal relationships and long-term impact of technological factors on energy security and energy equity. Zhang and Yang (2024) research synergy between energy security and collective management of carbon dioxide emissions. Authors propose recommendations only for sequenced activities for energy security and sustainable economic development. Mersch, Caton, Markides, and Dowell (2024) outline that net-zero transition is not in tension with energy security, but appropriate energy policy is required, as the cost optimal solution shows poor resource import diversity. The paper has limitations connected with electricity grid infrastructure, digital infrastructure, and control systems. Adedeji, Ogunbayo, Ajayi, and Adeniyi (2024) define five measures of energy security (accessibility, affordability, acceptability, availability, developability) and four measures for governance quality to reduce carbon emissions. The future work aims exploring the potential of renewable energy sources (and their management), revisit emission effects and diversification of energy mix by investing in energy storage technologies. Aslam, Yang, Arslan, and Ashraf (2024) recommend eco-friendly policy framework to minimize energy related risks, achieving a balance between energy needs for development and environmental sustainability. There are no considerations about technological management innovations. Xie and Xie (2024) express variations in amplitude and trajectory of climate changes. Thence a short- and a long-term policy for achievement of energy security must be developed. Chan, Punzi, and Zhao (2024) present a model for environmental evaluation of geopolitical conflicts and prioritize energy security and resilience. Authors recommend investments in renewable energy technologies, but there are no ideas about their management. Pata and Karlilar (2024) investigate the fossil fuel material footprint (FMF) for 24 OECD countries. Green innovation (GI) and energy security risk reduce fossil fuel material footprint. Increasing energy security risk index reduces the material footprint. Authors recommend that OECD policymakers pay attention to ensuring energy security to reduce the material footprint by expanding renewable resources and allocate more economic resources to green innovations with higher returns. Future studies can investigate the impact of the GI dimension of R&D expenditures on FMF, especially on energy efficiency and Renewable Energy resources.

- Economics and Policy for energy security

Fouladvand, Sarı, and Ghorbani (2024) introduce the term: collective energy security. Four measures (energy efficiency, governance, environment, and social effects) are crucial for the community energy systems. The highest priority has the dimension infrastructure, but there are no suggestions about its management. Zhi, Zhang, Kang, and Fang (2024) suggest a frame for evaluation of regional energy security. Authors integrate energy equity for quantity estimation of energy security. The result is that the usage of renewable energy is crucial, but there are no directions for management of modern energy sources. Li, He, Zhang, and Xia (2024) highlight a significant linear correlation between energy synergy between provinces in China’s Yangtze River Delta region. The findings highlight supply security as the central concern for safeguarding energy security. There are no details about energy coordination mechanisms. Siksnelyte-Butkiene, Streimikiene, Lekavicius, and Balezentis (2024) analyse and rank composite energy security indicators and frameworks based on their integrity. 40 different composite indicators are evaluated. Six out of 40 indicators appear as those of very high integrity. An interdisciplinary approach addresses the problem and is moving towards a general understanding that energy security does not solely relate to the accessibility and affordability of energy resources. Stepanov, Teschner, Zemah-Shamir, and Parag (2024) state energy security as solar and wind self-sufficient generation. By solar and wind energy-deficient generation could occur disruptions: high imports of low-carbon technology and of crucial metals and high imports of carbon- and energy-intensive goods. The suggested solution is a higher reliance on distributed renewable energy sources and their interconnections. Dagar, Dagher, Rao, Doytch and Kagzi (2024) name energy diversification (ED) in presence of high economic policy uncertainty as essential factor for energy security. To obtain a sustainable level of ED, policymakers should increase investment in gross (fixed) capital formation. This will result in balance between energy security and environmental sustainability. Wang, Dong, Zhong, Zhao (2024) answer both questions: (1) How does High-quality Energy Development (HED) win from energy security? Energy security encourages collaboration between international energy companies and technology providers. (2) How does energy security win from HED? HED encourages research, development, and application of renewable technologies (and their management). Sohail and Md Din (2024) identify the circularity between digital finance systems, energy security, and mineral resources trade. The mining industry saves on currency conversion and transaction fees and is more included in cross-border transactions. Energy security forces nations to diversify their energy sources. The demand of certain minerals, used in renewable energy technologies, rises, for example lithium for batteries or rare earth elements for wind turbines and electric cars. Lee, Yuan, He, and Xiao (2024) illustrate that geopolitical risk (GPR) causes the U-shape effect on energy security (ES) that first decreases ($GPR < 0.59$) and then increases ($GPR > 0.59$), meaning that GPR causes both negative and positive effects on ES. Analysis indicates that renewable energy technology innovation is the key transmission mechanism for the U-shape of this process.

- Emerging Technologies for energy security

Kong, Wei, and Zhao (2024) explain that a hybrid pool-based electricity retail market approach is utilized to optimize energy security, supply, and consumption. The significant roles of Renewable Energy Sources (RES), storage systems, and Electrical Vehicles (EV) are highlighted in this context. A future research suggestion could focus on the development of a comprehensive framework for assessing the socio-economic and environmental impacts of integrating RESs, storage systems, and EVs into restructured power systems. Balakrishnan, Sharma, Bora, and Dizge (2024) express biomass energy appears as a robust answer amid rising climate change worries and the urgent demand for cleaner energy sources. AI technologies become drivers of innovation for nearly perfect energy yield. However, data security and AI ethics remain a challenge. Future trends in machine learning and AI for biomass energy are: Explainable Artificial Intelligence (XAI) for Transparency, Autonomous system and Personalized Energy Consumption. Khan, Khurshid, Cifuentes-Faura, and Dai (2024) show that negative climate changes increase Renewable Energy mixes and impacts energy security. Therefore, the outcomes of this study recommend developing a comprehensive (national) plan to increase renewable energy use. Gritz and Wolff (2024) propose following technological news for ensuring energy security in Europe: (1) Germany as a transit hub for Norwegian gas and LNG (Liquefied Natural Gas); (2) New LNG capacity in Poland, the Baltics, Southeastern Europe; (3) Economic interdependence for ensuring cross-border gas flows; (4) Expansion of renewables and energy saving.

Figure 2 shows distribution of energy security articles by content.

In all these articles there are no details about Man-AI Interface by searching energy security in different conditions: environmental commitment, failures, cyber-attacks, usage, and pricing. The author prioritizes development of scenarios for AI agents' application in ensuring energy security. The article is intended to students, university professors, and business managers.

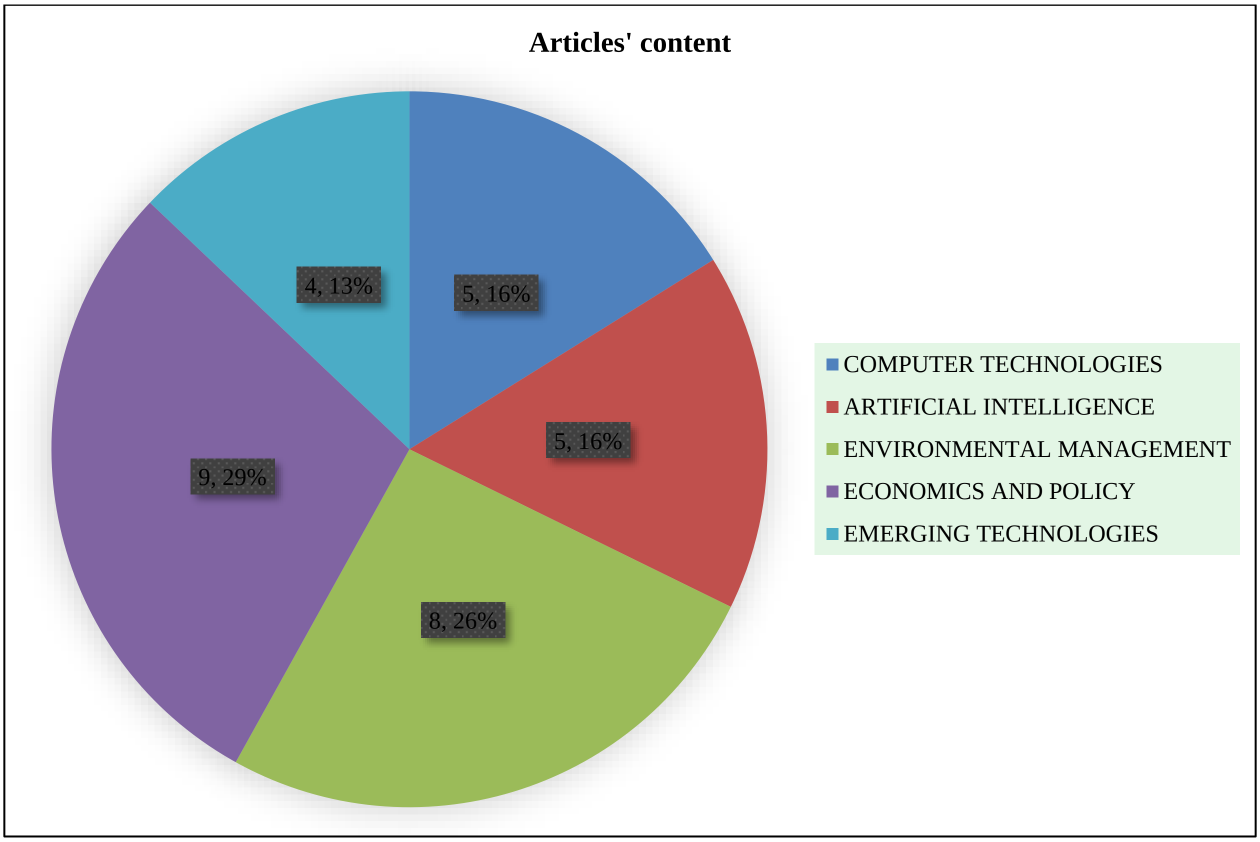

Figure 2. Distribution of energy security articles by content.

Methodology

To fulfil a particular task, AI agents usually follow a three-part method (Caballar, 2024).

(1) They determine the goal through a user-specified prompt.

(2) They figure out how to approach that objective by breaking it down into smaller, simpler subtasks and collecting the needed data.

(3) Finally, they execute tasks using what's contained in their knowledge base plus the data they've amassed, making use of any functions they can call or tools they have at their disposal.

Results

The results include examples for AI application in searching energy security: (1) Booking of desired electricity quantity from clean (renewable) source; (2) Booking of electricity by failure (bad weather) forecast; (3) Booking of electricity by cyber-attack forecast; (4) Booking of electricity with desired performance (quantity); (5) Booking of electricity at lowest price.

The Booking of desired electricity quantity from clean (renewable) source follows the algorithm:

- An AI agent might first search the web for all renewables for A kWh in B region on Y date,
- Scan the search results and,
- Select the lowest-priced renewable,
- The agent then calls a function that connects to the application programming interface (API) of the renewable booking platform.

- The agent makes a booking for the chosen renewable, entering the user's details based on the information stored in its knowledge base.
- The booking AI agent might be instructed to notify the user if the cheapest renewable has no available capacity, allowing the user to decide on the next step.

Figure 3 shows the activity diagram for Booking of desired electricity quantity from clean (renewable) source.

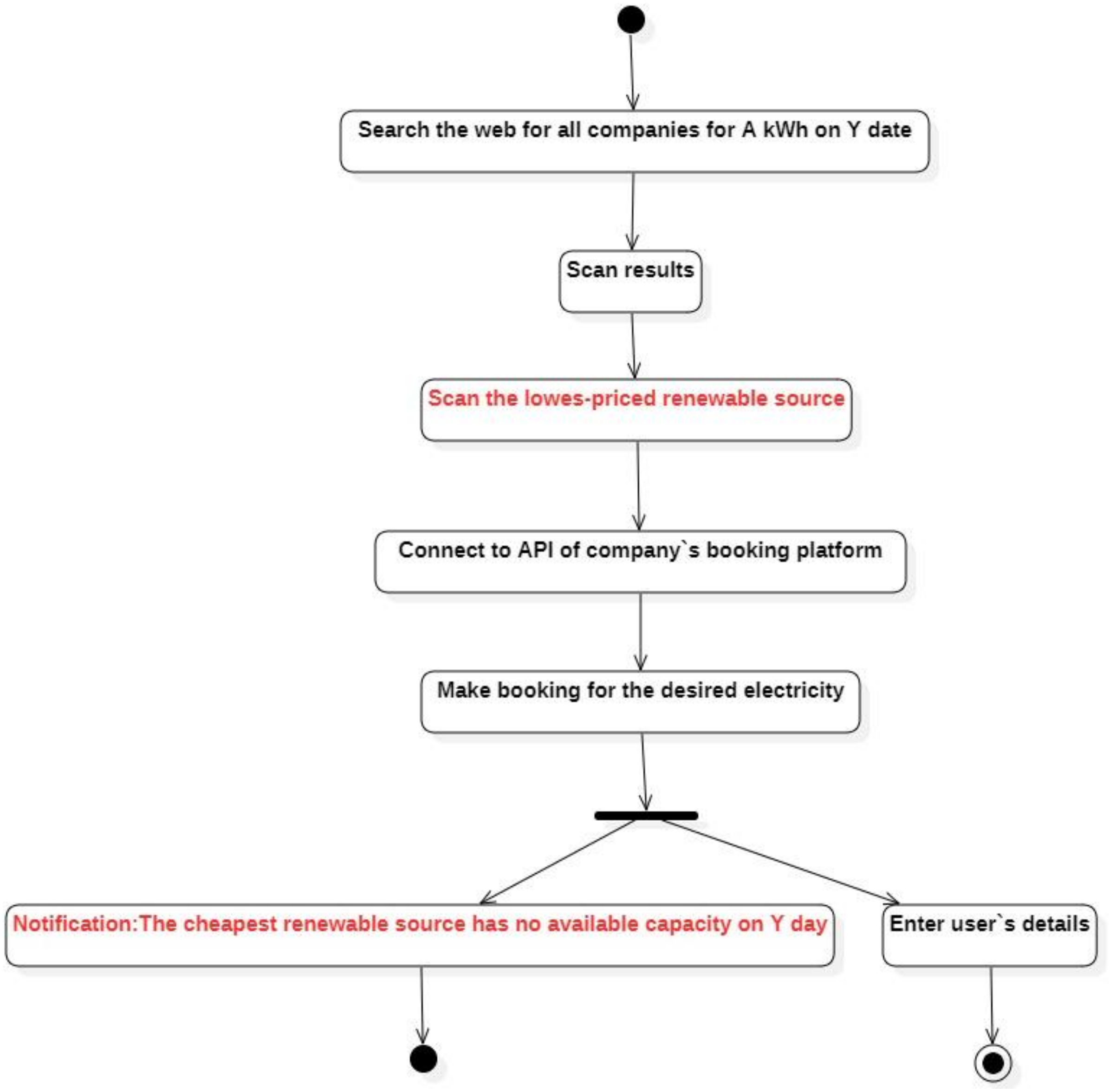

Figure 3. Activity diagram for Booking of desired electricity quantity from clean (renewable) source.

Similarly, Figure 4 depicts Booking of electricity by failure (bad weather) forecast, Figure 5 illustrates Booking of electricity by cyber-attack forecast, Figure 6 highlights Booking of electricity with desired performance (quantity), and Figure 7 outlines Booking of electricity at lowest price.

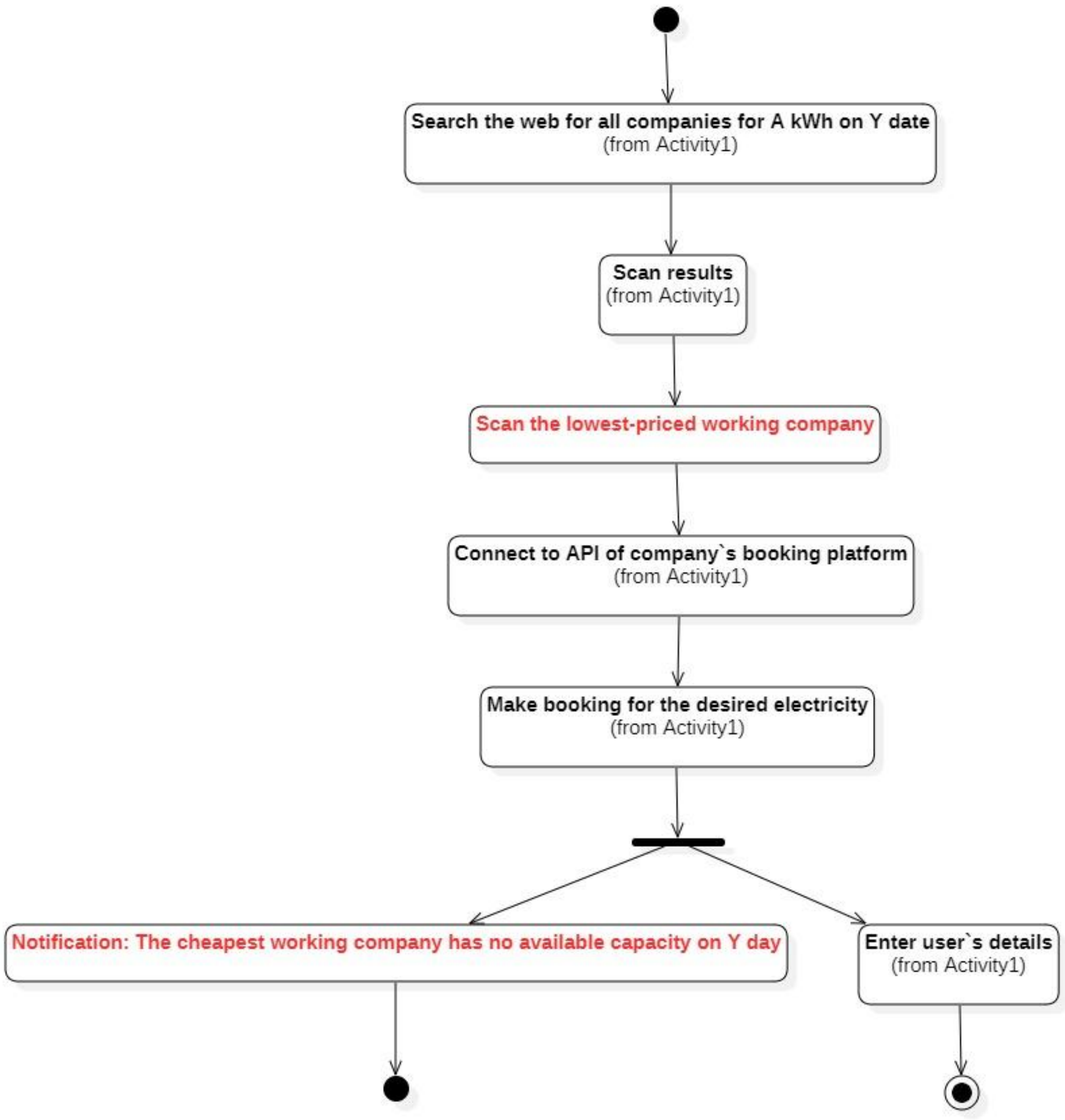

Figure 4. Activity diagram for Booking of electricity by failure (bad weather) forecast.

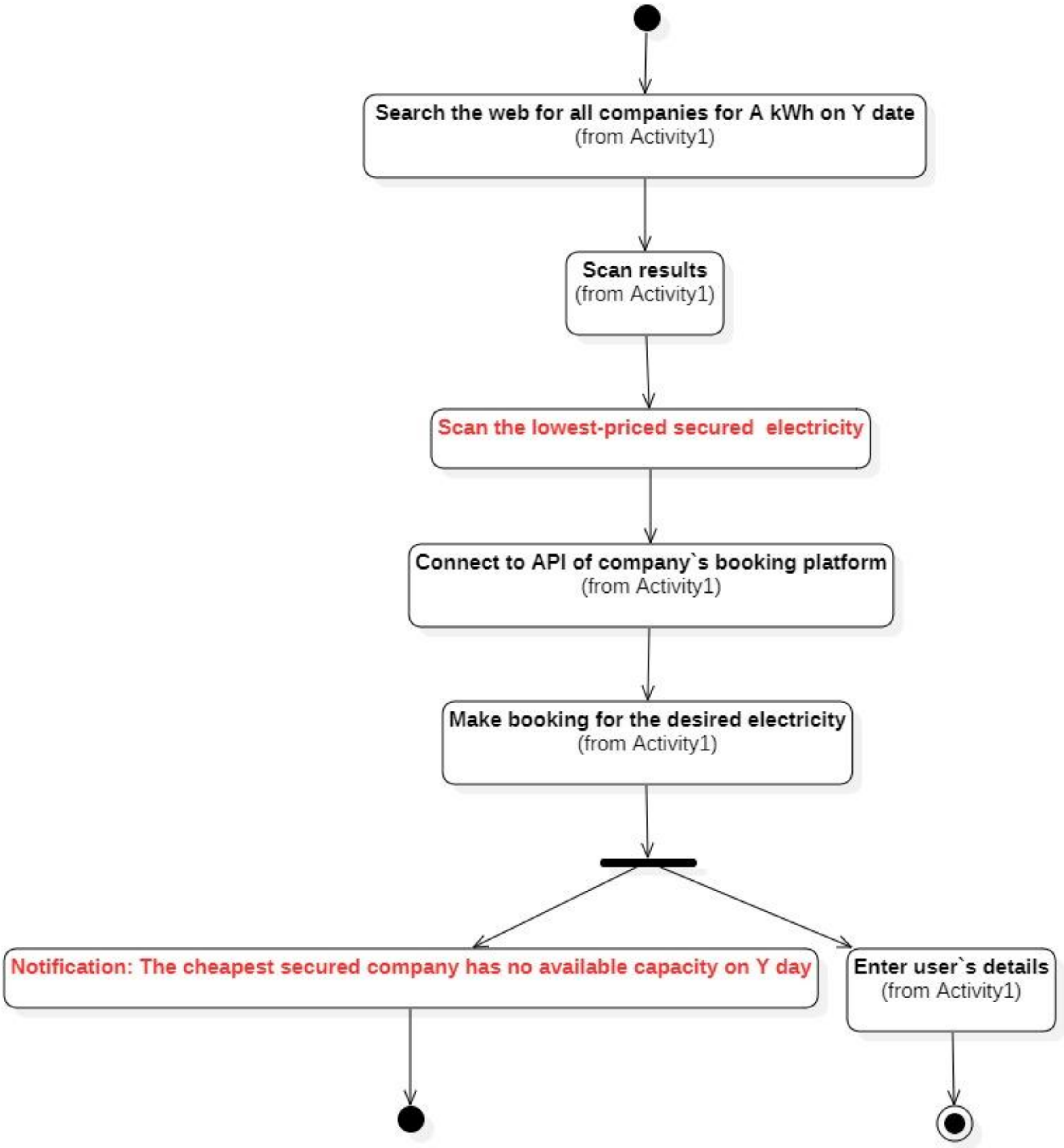

Figure 5. Activity diagram for Booking of electricity by cyber-attack forecast.

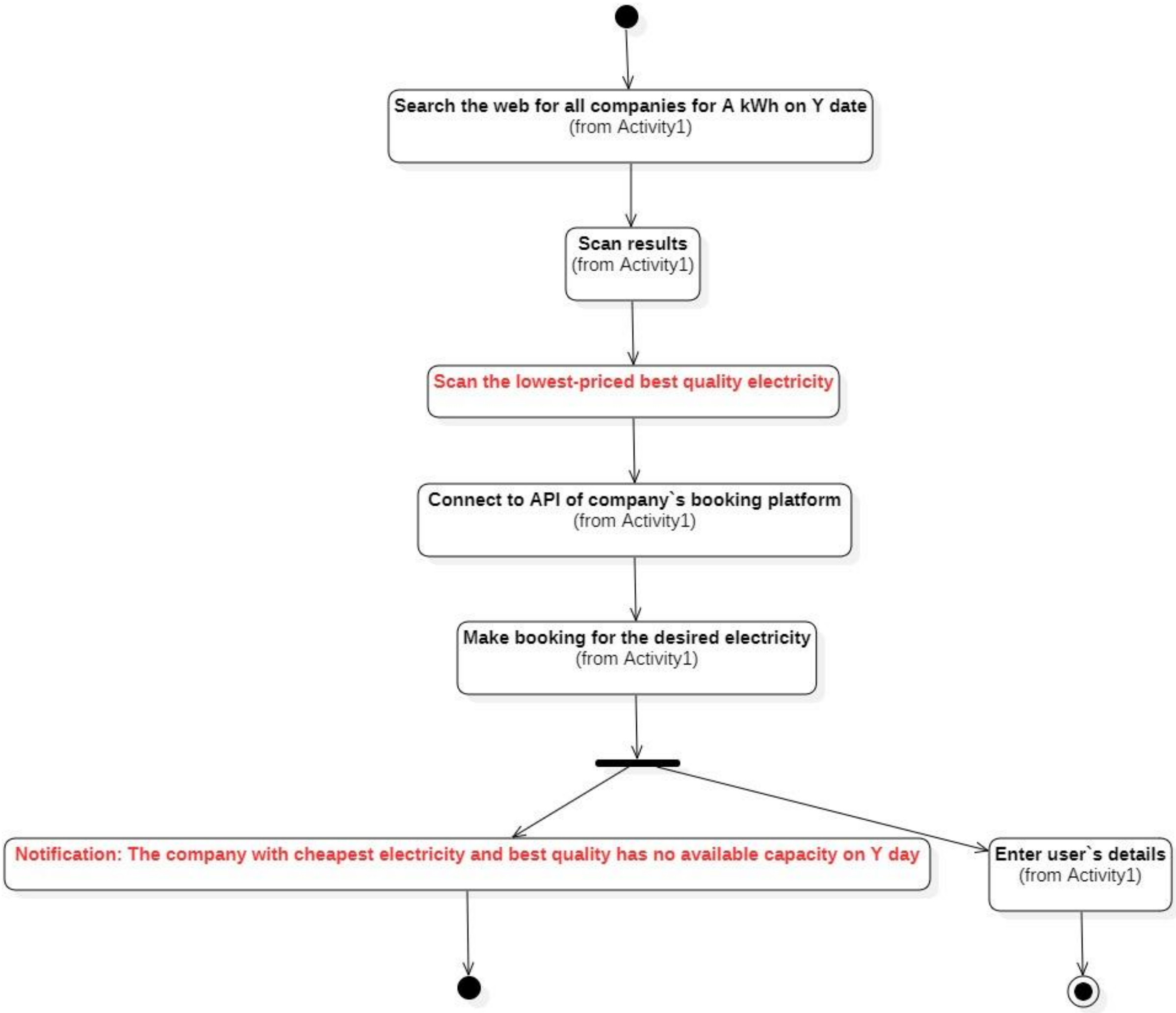

Figure 6. Activity diagram for Booking of electricity with desired performance (quantity).

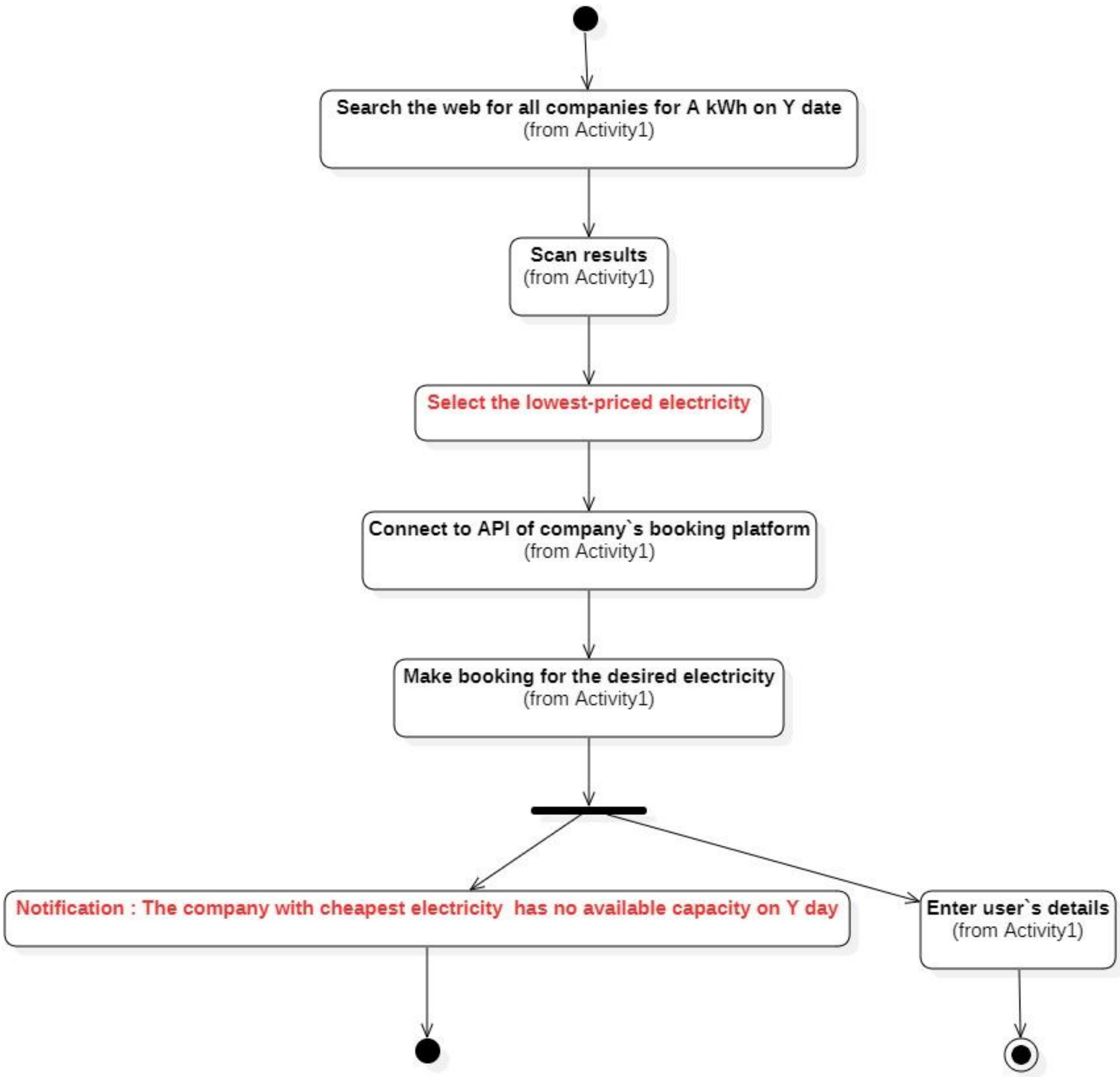

Figure 7. Activity diagram for Booking of electricity at lowest price.

Conclusion

AI agents are at the beginning of their application. They have a lot of disadvantages and the most significant are:

- Weak security: Agents could be used in an improper way. For example, they pull out personally identifiable information, and format it into a command that leaks the data to an attacker's server.
- Factual accuracy: Factual accuracy is another issue for AI agents, since they're built on LLMs that have a problem with hallucinations—the technical term for making things up.

Even though AI agents have their place in ensuring energy security. "In front of the electricity meter" their importance is not proven yet, but behind the electricity meter (demand side) their prominence is enormous.

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