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Evolution of Demand Response: A Historical Analysis of Legislation and Research Trends

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***Abstract*—In the past two decades, interest in demand response (DR) schemes has grown exponentially. The need for DR has been driven by sustainability (environmental and socio-economic) and cost-efficiency. The main premise of DR is to influence the timing and magnitude of consumption to match energy supply by sharing the benefits with consumers, ultimately aiming to optimize generation cost. As such, the first and primary enabler to DR was the establishment of contemporary electricity markets. Increased proliferation of Distributed Energy Resources (DER) and microgeneration further motivated the participation of consumers as active players in the market, popularizing DR and the wider category of Demand-Side Management (DSM) programs. Smart Grids (SG) have been an enabler to modern DR schemes, with smart metering data providing input to the underlying optimization and forecasting tools. The more recent emergence of the Internet of Energy (IoE), seen as the evolution of SG, is driven by increased Internet of Things (IoT)-enabling and high penetration of scalable and distributed energy resources. In this IoE paradigm being a fully decentralized network of energy prosumers, DR will continue to be a vital aspect of the grid in future Transactive Energy (TE) schemes, aiming for a more user-centered, energy-efficient, cost-saving, energy management approach. This paper investigates original motives and identifies the first mentions of DR in the legislative and scientific literature. Afterwards, the evolution of DR is tracked over the past four decades, attempting to study the co-influence of legislation and research by performing a thorough statistical analysis of research trends on the IEEE Xplore digital library. Finally, conclusions are made as to the current state of DR and future prospects of DR are discussed.**

***Keywords*—Demand Response; Demand-Side Management; Smart Grids; Energy Markets; Power Systems; Legislation.**

I. Introduction

A. Problem Definition

Conventional electrical power systems were designed with over-dimensioned generation capacity to provide for peak load. Presently, around 20% of generation capacity is used exclusively for peak demand periods, accounting for 5% of the year [1]. By analyzing wholesale price duration curves such as in [2], one can calculate that those 5% of annual demand (18 days) exhibit hourly electricity prices reaching more than six times the average price. Another calculation would indicate that one in every ten Euros of the average annual electricity wholesale price is due to costs associated with peak demand periods.

Peak demand price spikes are due to the economics of energy generation and supply. Baseload power plants are generally ones with high capital investment and low running costs (e.g. steam, nuclear, and hydroelectric). Peaking power plants generally have lower capital investment and high running costs, with fast start-up being a necessity to respond to sudden demand peaks (e.g. gas and diesel generators) [3]. On a year-average, baseload power plants operate at a load factor of 85%, with the overall load factor of the generation capacity being at 55% [4]. Power plants at lower load factors operate less efficiently which results in higher cost per unit of generated electricity. Consequently, in peak demand periods caused by sudden imbalance of supply and demand (e.g. unforeseen rise in demand, unforeseen fall in supply, or transmission failure), price spikes in a spot market occur as generators have an opportunity to compensate losses in off-peak periods [5], [6]. Furthermore, thermal peaking plants operating at low annual load factors increases their CO_2 and greenhouse gas emissions [7], [8] and thus current power systems also have an environmental problem aside from being economically inefficient with most generation capacity being redundant.

While large-scale renewable energy sources (RES) are increasingly used as an economic low-emission alternative for both baseload and peak generation (mainly solar and wind) [3], their intermittent, non-dispatchable, stochastic, and geographically-constrained nature does not make them a reliable solution [9]. Meanwhile, although they result in a direct reduction of emissions, RES do not contribute to power system inertia (although synthetic inertia may be used with wind farms, it does not equal that of traditional generation [10], [11]), and thus create a need to maintain spinning and non-spinning reserves which indirectly, once again, increase the cost and emissions of the power system [12]. Therefore, the problem can be summarized in the following points:

- Electric generation capacity is planned according to peak demand, which constitutes only 5% of the year.
- 20% of total installed generation capacity is only used during peak demand periods.
- The average annual load factor of total installed generation capacity is 55%.
- Lower LF means lower efficiency, which results in higher cost and emissions per unit generated electricity.
- RES decrease emissions but are unpredictable and geographically constrained, making them unreliable.

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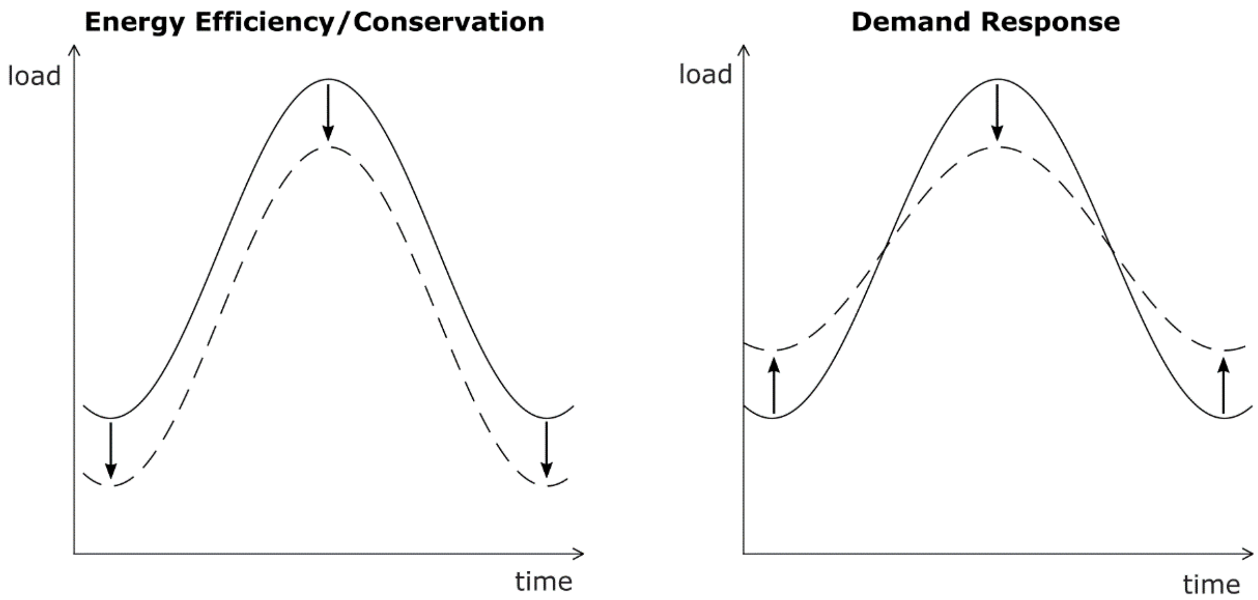

Fig. 1. Comparing two DSM Approaches: Energy Efficiency/Conservation vs Demand Response.

- RES decrease inertia, so it's necessary to still maintain reserves (i.e. RES cannot completely replace reserves).

B. *Demand Response as a Solution*

During the 1990's the proliferation of distributed energy resources (DER) and distributed generation (DG) have made electricity consumers increasingly active participants in power generation. This, occurring simultaneously with the electricity market liberalization movement globally, has ignited a shift from the supply to the demand side, viewing electricity consumers as active participants in the industry. As such, interest in demand-side management (DSM) has grown exponentially. With the subsequent rise of Smart Grids (SG) and advanced communication infrastructures, DSM approaches have become more sophisticated and capable of dramatically enhancing power system efficiency. There are three main categories of DSM: 1) On-Site Backup and Storage, 2) Energy Efficiency and Conservation, and 3) Demand Response (DR) as can be seen in Figs. 1 and 2. Some studies seem to use both terms interchangeably and the source of this confusion is caused by the early development stages of DSM and DR. This historical confusion leads to some authors interchangeably using DSM and DR and is elaborated in Section 3. However, the current official definitions both in academic literature and in legislation are that DR is a subset of DSM [13]–[15].

DSM approaches deal with the broader perspective of managing and decreasing energy consumption from the consumer-side.

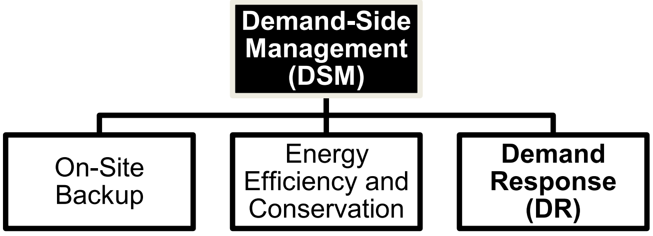

Fig. 2. Relationship between DSM and its subsets: On-Site Backup (and Storage), Energy Efficiency and Conservation, and DR.

On-site backup provides capacity for demand-side generation and storage to participate in load-balancing or ancillary services. When DSM and DR are confused as previously highlighted, it is rather energy efficiency and conservation that is confused with DR. Fig. 1 highlights the difference between both approaches. While efficiency and conservation measures aim at reduction of overall electricity demand (baseline and peak alike), DR is concerned with specifically reducing peak demand, shifting load to off-peak periods and smoothing out the demand curve. This, as explained earlier, contributes to economic and environmental benefits and more reliable grid operation.

This paper presents a novel approach of analyzing DR: a thorough historical analysis of both legislative and scientific research literature. Section 2 identifies the origins of DR and DSM and initial motives for their inception. Section 3 presents a full review of relevant legislative (Section 3.1) and scientific (Section 3.2) literature in the past four decades. The latter Section also consists of an extensive analysis of research trends on the IEEE Xplore database pertaining to relevant technologies, showing co-influence of legislation and academic research on DR and a timeline of its evolution identifying important milestones. Section 4 provides conclusions for this work, identifies the current state of DR, and suggests future work.

II. ORIGINS OF DEMAND RESPONSE

For most of its history, the electric power industry was a monopoly, with electricity companies being largely state owned and vertically integrated (performing generation, transmission, and distribution). This is because economies of scale have historically been the main driver of the industry, and it was widely perceived that one large utility would be more efficient in delivering electricity demands rather than several competing smaller ones [16], [17].

During the 1970's technological advance caused generation economies of scale at the unit level to be exhausted at 500 MW [18], thereby dismantling the long-held natural monopolistic perception of energy generation [19]. Moreover, the 1960's and 1970's witnessed the beginning of global environmental awareness.

This subsequently manifested in enaction of government environmental policies, best characterized by the US Clean Air Act of 1970 [20] and the first European Action Program in 1973 [21], which both sought to restrict pollutants and greenhouse gas emissions. Meanwhile, the 1973 oil crisis raised concerns on security of electricity supply and the need to diversify the power generation mix, which was largely dependent on fossil fuels, to incorporate renewable and clean energy sources [22], [23].

This triad of events in the 1970's (economic viability of small generation units, environmental awareness of greenhouse gas emissions, and concerns on security of supply largely dependent on fossil fuels) sparked a global wave of electricity market reform bent on socio-economic and environmental sustainability of electrical power systems through two simultaneous motions: 1) deregulation, unbundling, and liberalization of the electricity industry, and 2) incorporation of clean and renewable energy sources into the energy mix. The atmosphere created by the combined effect of competing electric utilities and proliferation of small renewable generation made it necessary to start considering the demand side as active participants in the electricity industry rather than passive users. It was during this period that the evolution of DSM (and subsequently DR) as an effective policy began.

Two main historic drivers of DSM and DR were identified: 1) Markets and Legislation and 2) Scientific Research; and the progress of DR was tracked in both through the past four decades to highlight its evolution from its origins to the current state.

III. Historical Evolution of Demand Response

A. Markets and Legislation

After the investigation of DR origins in the previous Section, it was possible to name three major players: USA, UK, and the EU to focus on; as they were the first to incentivize and implement DSM programs in general and DR programs in particular; and continue to be top influencers of global energy markets and policies.

By surveying the full body of legislative and statutory publications of the USA, UK, and EU pertaining to energy and electricity, it was possible to propose a general classification of five stages in the development of DR programs in legislation:

Stage 1) Market deregulation/liberalization;

Stage 2) Incentivization of RES and DG/DER;

Stage 3) Implementation of DSM programs for energy efficiency and decreased emissions;

Stage 4) Usage of Smart Meters (SM) and emergence of DR capability as an additional DSM tool;

Stage 5) DR programs in Smart Grids (SG).

The following Sections present all energy and electricity-related legislation for the USA, UK, and EU, identifying the legislations corresponding to the above five stages.

1) United States of America (USA)

The USA has been the pioneer in electricity market deregulation and liberalization. It is often mentioned in literature that the first case of market liberalization happened in Chile by the Chile Electricity Act of 1982 [2], [24].

However, that was found to be preceded by the Public Utility Regulatory Policies Act [25] in the USA in 1978; which is the first case of legislation found allowing non-utility generators to participate in an electric power market. While this opened the door to a quasi-deregulated/liberalized US electricity market, it wasn't until 1992 [26] that it was fully so on the federal level.

It is important to mention that in the USA there is a distinction between federal law and state law, so while this directs federal activities and strategies individual states have a good degree of independence as to the degree of regulation they have on local electricity markets. This was particularly evident after the California crisis in 2001, when many states chose to reverse or slow down their motion towards deregulation at the time [17].

The first mention of DR in legislation was also found in USA Energy Policy Act of 2005 [27]:

"install time-based meters and communications devices for each of their customers which enable such customers to participate in time-based pricing rate schedules and other demand response programs."

This coincides with the first mention of DSM; I.e., DR was the first DSM measure mentioned by USA legislation. All legislations including subsequent ones which direct the development of USA's DR national action plan, in addition to rollout of SM and SG were detailed in Table I [25]–[29].

2) United Kingdom (UK)

The UK swiftly followed the US in implementing market liberalization policies in 1989 [30]. In 2006, "dynamic demand technologies" were first mentioned [31]:

"contribution ... being made by dynamic demand technologies to reducing emissions of greenhouse gases in Great Britain."

TABLE I. List of US Legislations Pertaining to Development of DSM and DR.

Year	Legislation Title	Description
1978	**Public Utility Regulatory Policies Act** [25]	- Allowed "non-utility generators" to participate in energy supply - Created an electric power market with "non-utility generators"
1992	**Energy Policy Act of 1992** [26]	- Energy deregulation / allowing private competition in wholesale market - Incentivize renewable energy production
2005	**Energy Policy Act of 2005** [27]	- Incentivize installation of Smart Meters (first mention of SM) - Incentivize participation in demand response programs, and request a study of the potential benefits of DR (first mention of DR) - Incentivize renewable energy production via tax incentives
2007	**Energy Independence and Security Act of 2007** [28]	- Directs developing DR programs to reduce peak loads and increase energy efficiency; requests a study on the use of DR to provide ancillary services - Directs the establishment of a SG infrastructure (first mention of SG), and provide funding for Smart Grid applications - Increase taxes on oil industries and promote renewable energy sources
2009	**American Recovery and Reinvestment Act of 2009** [29]	- Significantly increase funding and incentives for Smart Grid applications

While this corresponds to DR by current definitions, the objective was in fact to implement DSM with an environmental focus rather than an economic one (as was the case with USA). All relevant legislation for the UK was listed and cited in detail in Table II [30]–[33]. The first literal mention of DR only came much later, in 2011 [33].

3) European Union (EU)

The EU was the last of the three to liberalize electricity markets, doing so in 1996 [34]. At the same time, it was the first to mention DSM programs [35]:

"'energy efficiency/demand-side management' means a global or integrated approach aimed at influencing the amount and timing of electricity consumption in order to reduce primary energy consumption and peak loads by giving precedence to investments in energy efficiency measures, or other measures"

In the beginning, DSM in the EU was confined to (the term even used interchangeably with) energy efficiency and conservation (Fig. 2). Same as the UK (part of EU at the time despite not being in Eurozone or EEA), the focus of EU was directed towards environmental sustainability and security of supply, opposed to more economic and profit-driven US motives (although all three share security of supply as a common motive). This is more evident by realizing that despite being the first to mention DSM in legislation, EU was the last to mention DR in 2012, as shown in Table III [34]–[38].

TABLE II. LIST OF UK LEGISLATIONS PERTAINING TO DEVELOPMENT OF DSM AND DR.

Year	Legislation Title	Key Relevant Points
1989	**Electricity Act 1989** [30]	- Liberalization of electric power generation in the UK
2006	**Climate Change and Sustainable Energy Act 2006** [31]	- Promotion of microgeneration / renewable sources - The capacity of "dynamic demand technologies" to reduce greenhouse gas emissions is requested to be reported, and is defined (first mention of DR)
2008	**Energy Act 2008** [32]	- Licensing Smart Meters (first mention of SM) - Licensing Feed-in-Tariffs (FiT) for small-scale generation
2011	**Energy Act 2011** [33]	- Requested an assessment of, and defining, "demand side response" (first literal mention of DR)

TABLE III. LIST OF EU LEGISLATIONS PERTAINING TO DSM AND DR

Year	Legislation Title	Description
1996	**Directive 96/92/EC** [34]	- Liberalization and unbundling of electric utilities - Establishing the European internal electricity market
2001	**Directive 2001/77/EC** [35]	- Targets for renewable energy generation
2003	**Directive 2003/54/EC** [36]	- Expanded liberalization and unbundling of electricity market - Directs the use of Demand-Side Management (first mention of DSM)
2009	**Directive 2009/28/EC** [37]	- Set EU 2020 strategy with 20% target for renewable energy generation, emissions reduction, and consumption reduction - Set 80% target for consumers with SM by 2020 (first mention of SM) - Suggests the use of FiT to promote small-scale renewable generation
2012	**Directive 2012/27/EU** [38]	- Directs use of DR (first mention of DR) - Deployment of SG (first mention of SG)

B. Scientific Research

To study the scientific research trends during the same time period, a Python web-crawler was developed and was used to track the exact volume of literature pertaining to keywords/technologies identified as directly influential to development of DR on the IEEE Xplore digital library.

Fig. 3 shows that research on DG began in 1990 during the wave of energy market liberalization and after DSM has been studied in literature since 1985. DER first appeared in literature in 2000, after market liberalization. This is probably due to motivations to micro-generate and store energy amidst liberal markets. Sparked by EU directive 2001/77/EC and the UK Climate Change & Sustainability Act, research on MG began in 2001 and started increasing in 2005, respectively. EU Directive 2009/28/EU (promoting small-scale generation), as expected, tended to mark an exponential growth in research on both MG and DER.

Fig. 4 shows that although DR research began in 1989 and SG in 1997, the two only started to increase significantly together, with DR being an essential component of the SG [40]. Being low voltage distribution grids capable of operating isolated from the main grid and acting as a controllable load, SG were an essential part of DSM development [39].

The series of legislations by the USA, UK, and EU as shown in the figure clearly ignited the growth of scientific research on both SG and DR. The figure also shows the volume of correlated research (DR & SG), with 40% of all DR research currently being directly related to SG applications. This suggests that currently, DR is heavily influenced by SG technologies and grid architectures.

Increased IoT-enabling of SG and high penetration of scalable and distributed energy resources in recent years is resulting in the emergence of the Internet of Energy (IoE) [41]. In this IoE paradigm being a fully decentralized network of energy prosumers, DR will continue to be a vital aspect of the grid in future Transactive Energy (TE) schemes [42], which aim for more user-centered, energy-efficient, cost-saving, energy management approaches [43], [44].

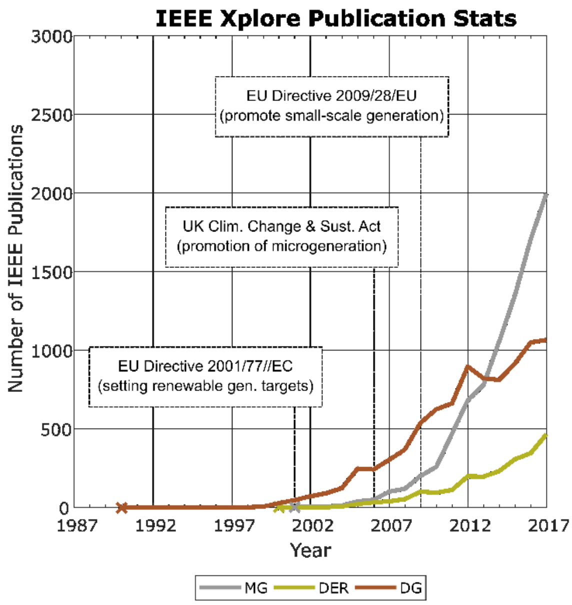

Fig. 3. Research trends on IEEE Xplore for MG, DER, and DG.

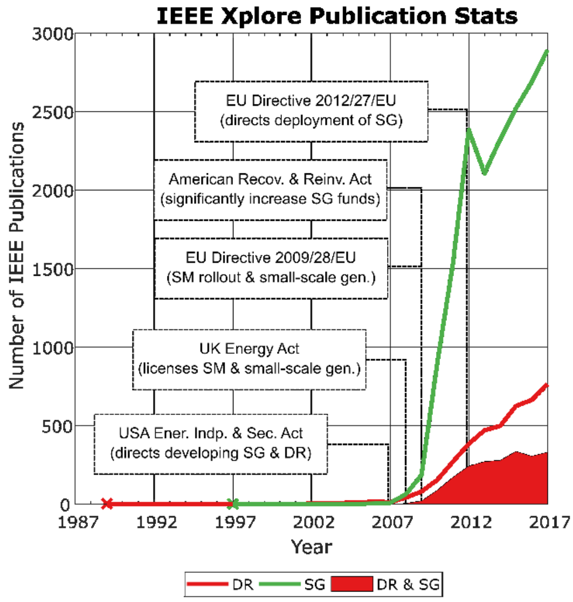

Fig. 4. Research trends on IEEE Xplore for DR, SG, and DR correlated with SG (DR & SG).

Finally, the legislation and scientific research trends were combined in a complete timeline for the historical emergence and evolution of DR (Fig. 5), incorporating all milestones from previous analyses. The timeline provides a clearer visualization of the reasoning given in the previous section about USA being more economically-driven while the EU being more environmentally driven, shown by the emergence of DR much later in the EU, in-line with the expectation of [45].

IV. Conclusions

This paper presented a novel, thorough, and historical analysis of DR as a vital DSM approach. The origins of DR were investigated along with the original motives for its inception. USA, UK, and EU were identified as the pioneers of DSM and DR. Afterwards, an extensive historical review of their legislations was performed, identifying all relevant legislation and milestones in the evolution of DR. A python web-crawler was used to track research trends on IEEE Xplore for relevant technologies, and a comparative analysis was performed between legislation and research trends. A clear co-influence between both was demonstrated, and regional differences were highlighted. With DR currently intertwined with SG, the methodology used in this work should be extended to investigate the evolution of SG and subsequently DR into an IoE paradigm with TE schemes as a result of IoT-enabling.

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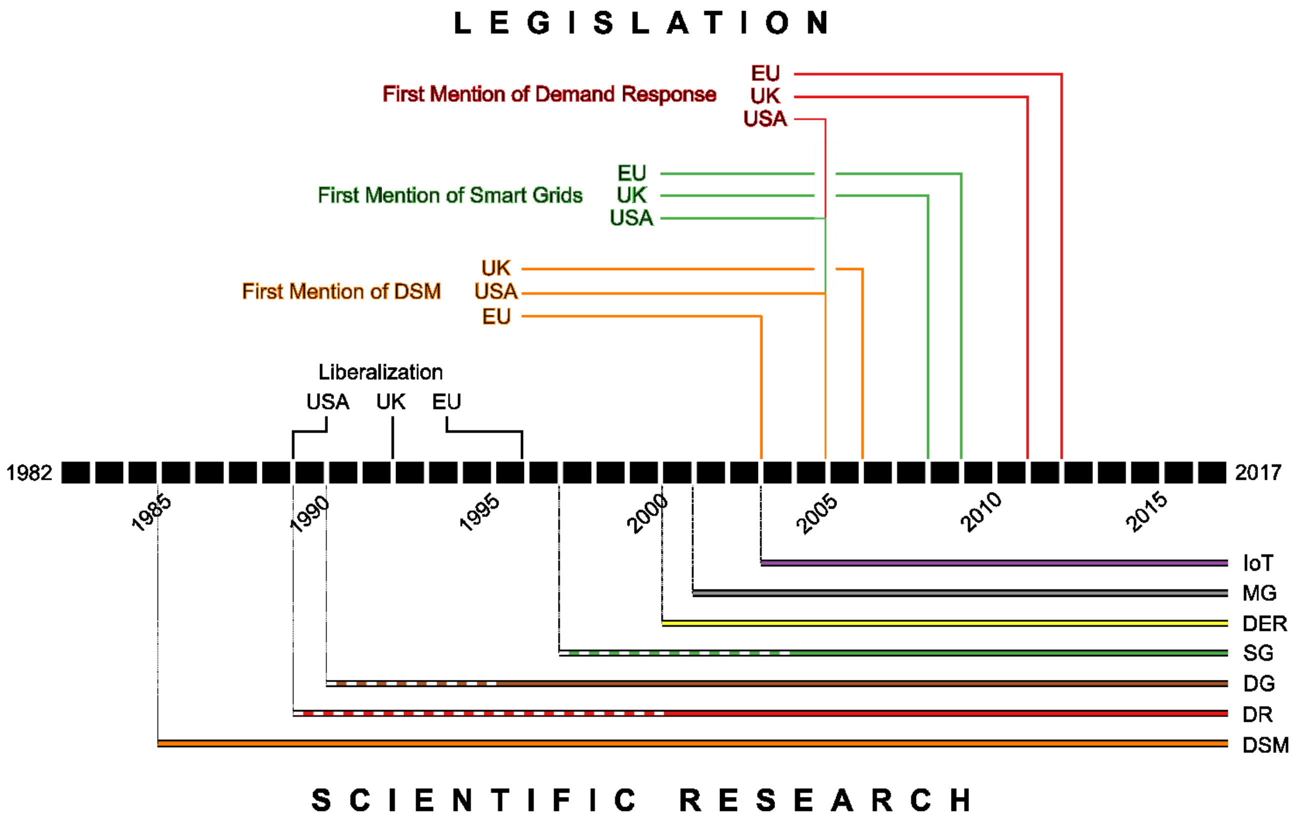

Fig. 3. Timeline showing all important legislative milestones (top) and tracking scientific research on IEEE Xplore (bottom) for each topic/technology of relevance to DR and DSM development (dashed lines mean discontinuous research i.e., <1/year)

References

[1] N. Bassamzadeh, R. Ghanem, S. Lu, and S. Jalal, "Robust scheduling of smart appliances with uncertain electricity prices in a heterogeneous population," *Energy Build.*, vol. 84, pp. 537–547, 2014.

[2] R. Green and I. Staffell, "Electricity in Europe: exiting fossil fuels?," *Oxford Rev. Econ. Policy*, vol. 32, no. 2, pp. 282–303, 2016.

[3] G. M. Masters, *Renewable and Efficient Electric Power Systems*. John Wiley & Sons, Inc., 2004.

[4] G. Strbac, "Demand side management: Benefits and challenges," *Energy Policy*, vol. 36, pp. 4419–4426, 2008.

[5] J. Mullins, L. Wagner, and J. Foster, "Price Spikes in Electricity Markets: A Strategic Perspective," *Work. Pap., Sch. Econ. Univ. Queensland, Aust.*, no. 5, 2010.

[6] T. M. Christensen, A. S. Hurn, and K. A. Lindsay, "Forecasting Spikes in Electricity Prices," *NCER Work. Pap. Ser.*, 2011.

[7] CIAB, "Power generation from coal: measuring and reporting efficiency performance and CO_2 emissions," 2010.

[8] M. Steen, "Greenhouse gas emissions from fossil fuel fired power generation systems," 2001.

[9] H. T. Haider, O. H. See, and W. Elmenreich, "A review of residential demand response of smart grid," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 166–178, 2016.

[10] E. Muljadi, V. Gevorgian, and M. Singh, "Understanding Inertial and Frequency Response of Wind Power Plants," in *IEEE Symposium on Power Electronics and Machines in Wind Applications*, 2012, no. July.

[11] P. Fairley, "Can Synthetic Inertia from Wind Power Stabilize Grids?," *IEEE Spectrum*, Nov-2016.

[12] S. A. Pourmousavi, S. Member, and M. H. Nehrir, "Real-Time Central Demand Response for Primary Frequency Regulation in Microgrids," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1988–1996, 2012.

[13] P. Warren, "A review of demand-side management policy in the UK," *Renew. Sustain. Energy Rev.*, vol. 29, pp. 941–951, 2014.

[14] P. Warren, "Electricity demand-side management : best practice programmes for the UK," *WIT Trans. Ecol. Environ.*, vol. 176, pp. 69–80, 2013.

[15] M. H. Albadi, "A summary of demand response in electricity markets," *Electr. Power Syst. Res.*, vol. 78, pp. 1989–1996, 2008.

[16] M. Kopsakangas-Savolainen and R. Svento, *Modern Energy Markets: Real-Time Pricing, Renewable Resources and Efficient Distribution*. Springer Science & Business Media, 2012.

[17] L. Meeus, K. Purchala, and R. Belmans, "Development of the Internal Electricity Market in Europe," *Electr. J.*, vol. 18, no. 6, pp. 25–35, 2005.

[18] P. L. Joskow, "Productivity Growth and Technical Change in the Generation of Electricity," *Energy J.*, vol. 8, no. 1, pp. 17–38, 1987.

[19] F. A. Wolak, "Market Design and Price Behavior in Restructured Electricity Markets: An International Comparison," 2000.

[20] 91st Congress, *Clean Air Amendments of 1970*, no. C. USA, 1970, pp. 1676–1713.

[21] A. Jordan, "The implementation of EU environmental policy; a policy problem without a political solution?," *Environ. Plan. C Gov. Policy*, vol. 17, pp. 69–90, 1999.

[22] R. N. L. Andrews, *Managing the Environment, Managing Ourselves: A History of American Environmental Policy, Second Edition*. Yale University Press, 2006.

[23] European Environment Agency, "1970s," *Celebrating Europe and its environment*, 2007. [Online]. Available: https://www.eea.europa.eu/environmental-time-line/a-europe-of-firsts-environmental-achievements.

[24] Ministerio de Minería, *Aprueba Modificaciones Al D.F.L. N° 4, De 1959, Ley General de Servicios Electricos, En Materia de Energia Electrica*. Chile, 1982.

[25] 95th Congress, *H.R. 4018 - Public Utility Regulatory Policies Act*. US, 1978.

[26] 102nd Congress, *H.R. 776 - Energy Policy Act of 1992*. USA, 1992.

[27] 109th Congress, *H.R. 6 - Energy Policy Act of 2005*. USA, 2005.

[28] 110th Congress, *H.R. 6 - Energy Independence and Security Act of 2007*. USA, 2007.

[29] 111th Congress, *H.R. 1 - American Recovery and Reinvestment Act of 2009*. USA, 2009.

[30] *Electricity Act 1989, c.29*. UK, 1989.

[31] *Climate Change and Sustainable Energy Act 2006, c.19*. UK, 2006.

[32] *Energy Act 2008, c.32*. UK, 2008.

[33] *Energy Act 2011, c.16*. UK, 2011.

[34] European Parliament and European Council, *DIRECTIVE 96/92/EC*. EU, 1996.

[35] European Parliament and European Council, *DIRECTIVE 2001/77/EC*. EU, 2001.

[36] European Parliament and European Council, *DIRECTIVE 2003/54/EC*. EU, 2003.

[37] European Parliament and European Council, *DIRECTIVE 2009/28/EC*. EU, 2009.

[38] European Parliament and European Council, *DIRECTIVE 2012/27/EU*. EU, 2012.

[39] R. Venkatraman, S. Member, S. K. Khaitan, and S. Member, "A Survey of Techniques for Designing and Managing Microgrids," *Power Energy Soc. Gen. Meet. 2015 IEEE*, pp. 1–5, 2015.

[40] F. Shariatzadeh, P. Mandal, and A. K. Srivastava, "Demand response for sustainable energy systems: A review, application and implementation strategy," *Renew. Sustain. Energy Rev.*, vol. 45, pp. 343–350, 2015.

[41] M. Jaradat, M. Jarrah, A. Bousselham, Y. Jararweh, and M. Al-Ayyoub, "The internet of energy: Smart sensor networks and big data management for smart grid," *Procedia Comput. Sci.*, vol. 56, no. 1, pp. 592–597, 2015.

[42] Z. Liu, Q. Wu, S. Huang, and H. Zhao, "Transactive Energy : A Review of State of The Art and Implementation," in *2017 Chinese Automation Congress (CAC)*, 2017.

[43] K. Wang *et al.*, "A Survey on Energy Internet: Architecture, Approach, and Emerging Technologies," *IEEE Syst. J.*, pp. 1–14, 2017.

[44] N. Bui, A. P. Castellani, P. Casari, and M. Zorzi, "The internet of energy: A web-enabled smart grid system," *IEEE Netw.*, vol. 26, no. 4, pp. 39–45, 2012.

[45] N. G. Paterakis, O. Erdinç, and J. P. S. Catalão, "An overview of Demand Response: Key-elements and international experience," *Renew. Sustain. Energy Rev.*, vol. 69, p. 871–891, March 2017.