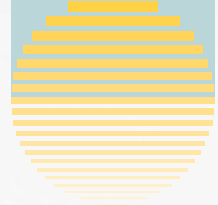


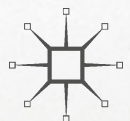
ENERGY,  
CLIMATE AND  
THE ENVIRONMENT



# Vehicle-to-Grid

A Sociotechnical  
Transition Beyond  
Electric Mobility

LANCE NOEL,  
GERARDO ZARAZUA DE RUBENS,  
JOHANNES KESTER,  
AND BENJAMIN K. SOVACOOOL



# Energy, Climate and the Environment

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Lance Noel · Gerardo Zarazua de Rubens  
Johannes Kester · Benjamin K. Sovacool

# Vehicle-to-Grid

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Electric Mobility

palgrave  
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## About This Book

This book defines and charts the barriers and future of an emerging low-carbon source of mobility that could dramatically reduce emissions, create revenue, and accelerate the adoption of battery electric cars: vehicle-to-grid technology. This technology connects the electric power grid and the transportation system in ways that will enable electric vehicles to store renewable energy and offer valuable services to transmission operators. To understand the complex features of this emergent technology, this book explores the current status and prospect of vehicle-to-grid and then individually details the sociotechnical barriers that may impede its fruitful deployment. Finally, the book concludes with a policy roadmap to advise decision-makers on how to optimally implement vehicle-to-grid and capture its benefits to society while attempting to avoid the impediments discussed earlier in the book.

This combines the most up-to-date literature on vehicle-to-grid, mobility, transitions, sociotechnical systems, and electric power systems along with original data collected by the authors on the array of challenges and benefits to vehicle-to-grid. The examples in the book cut across technical integration of research, economic analyses, and socio-political challenges based on novel mixed methods (quantitative and

qualitative). Thus, the book will ensure that readers from a variety of backgrounds will gain a more comprehensive understanding of vehicle-to-grid and its potential for wide-scale implementation in the transport and electric systems.



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Bill Clinton, the Prime Minister of Norway Gro Harlem Brundtland, and the late Nobel Laureate Elinor Ostrom have endorsed his books. Additionally, Prof. Sovacool is the founding Editor-in-Chief for the international peer-reviewed journal *Energy Research & Social Science*, published by Elsevier, and he sits on the Editorial Advisory Panel of *Nature Energy*.



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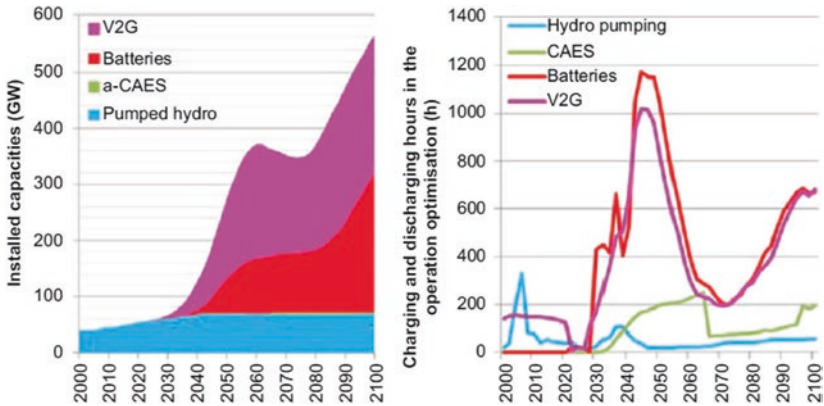
# Introduction: Vehicle-to-Grid and the Future of Electric Mobility

Vehicle-to-grid, often shortened to V2G, was first introduced as a concept near the turn of the twenty-first century to capitalize on the assumption that electric vehicles (EVs) would widely diffuse in society, and thus, there would be a large amount of electric power capacity that could provide valuable storage services to electricity grids [1]. Since its introduction, many have elaborated on the potential benefits of V2G, detailing the large amounts of power capacity, various electricity grid services, and economic revenues potentially available to EV owners [2, 3]. Given the disappointingly slow diffusion of EVs, V2G may prove useful to accelerate the adoption of EVs [4, 5]. While providing ancillary services for the grid, namely frequency regulation, and EV owner economic benefits are the most immediate benefits of V2G, the future benefits of V2G such as integrating renewable energy are also tantalizing. Indeed, a variety of papers have found that V2G can provide low-cost storage to integrate large-scale renewable electricity [6–8]), helping tackle the looming challenge of climate change as well as public health emissions from electricity and transportation sources.

Consequently, there has been increasing interest in the concept among industry and scholars, which has resulted in a variety of novel

potential solutions within electricity grids and transportation. In a recent literature review [9], the authors found around 200 articles published on V2G, covering a wide variety of concepts, including, but not limited to renewable energy integration, ancillary services, local grid solutions, microgrids, and buildings (see more about these research gaps in Chapter 8, the Conclusion). While the academic focus on V2G has continued to accelerate, the diffusion of the actual use of V2G has been more staggered historically, with current projects limited to only a few pilot projects within fleets around the world [9]. Nonetheless, these pilot projects are entering commercial operations, and there has been recent activity in project development, for example, with the UK government investing £30 million in projects focused on V2G in 2018 [10]. Even the Pope has supported and adopted EVs, which also included a project involving V2G [11].

Indeed, the future of V2G looks bright, with some scholars predicting that V2G will be an essential form of storage for the electricity grid of the future. For example, it has been predicted that there will be massive increases in V2G capacity in the coming decades, as shown in Fig. 1 [12], where it becomes a dominant technology in the power system. For this reason, and with the potential to decarbonize the electricity and transport



**Fig. 1** Installed capacity (left) and utilization per hour (right) during operation of a European grid optimized for different energy storage technologies, 2000–2100. CAES compressed air energy storage (Reprinted from [12])

sectors and drive EV adoption, the future of V2G is enticing to many actors. Specifically, experts envision V2G as a means to reach a future where there is a synergy between electricity and EVs, thereby feeding into imaginaries of synergy and seamless interconnectivity, as well of autonomy and self-determination [13]. While V2G exists today mostly in fleet pilot projects, its potential future is far-reaching and substantial, particularly when tapping into personal vehicles, public transportation, and perhaps more.

Thus, it is conceivable that in the future, V2G capability will become the norm (or at least in some markets and regions) and will be available in a variety of vehicles, becoming a part of everyday life in society. Despite the possible pervasiveness and benefits of V2G, outside of academia (and even within it), current knowledge and understanding of V2G are relatively low. In a recent survey conducted by the authors in the Nordic region, fewer than 10% of the respondents had ever heard of V2G before taking the survey [14, 15]. At the same time, academic knowledge of V2G is highly specialized, with most of the research effort taking place in highly technical fields within science and engineering [9], such as control charging optimization algorithms, renewable energy integration, and battery degradation.

Specialized knowledge alone, however, does not lead to broad diffusion of a new technology. It is well established in the innovation and transition literatures that for a technology to diffuse, knowledge about its benefits, use, and potential must be dispersed across a wider variety of actors than is currently the case for V2G [16]. Looking beyond academics and consumers, there will be an increasing number of other actors who will play an essential role in the diffusion of V2G, such as local and national policymakers, marketers, energy sector practitioners, fleet operators, or parking organizations, among various others. Therefore, for these actors, a basic understanding of V2G is essential.

For these reasons, we set out to write this extensive, comprehensive, and easily accessible reference on V2G. The book is aimed toward a wide audience including academics at the periphery of V2G, consumers interested in the technology that comes in their EV, policymakers who want to understand the technology to implement policies, and industry practitioners to understand the technology that may have

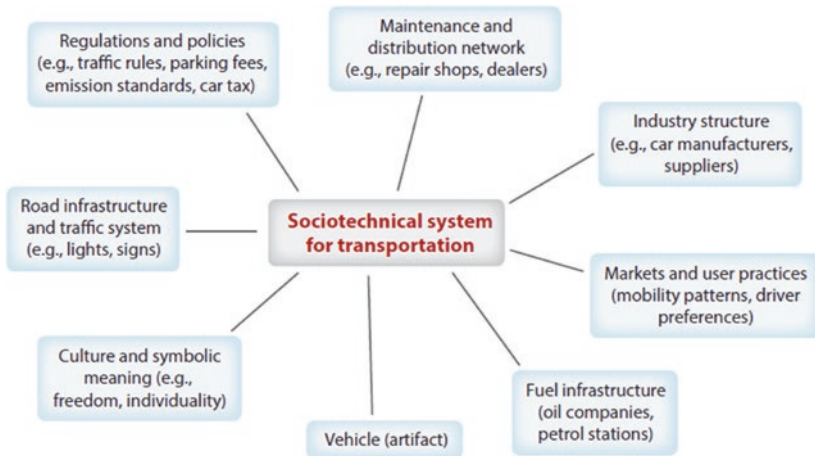


been recently implemented in their local grid. As the only other broad introduction to V2G is almost 10 years old [17], this book offers an up-to-date and more extensive introduction to a fast-moving technology that has changed substantially over the last 10 years. Moreover, to underscore the role played by the numerous sectors and actors in the complex sociotechnical system that V2G is interacting, we believe it is of the utmost importance to give a more comprehensive perspective of V2G. Consequently, as you make your way through the book, we will aim to provide the history and context of V2G, its potential future in better detail, and the challenges it may face from the variety of relevant perspectives. As the first chapters will extensively discuss the conceptualization and background of V2G, this introduction will introduce our approach to V2G, offer a brief introduction to the chapters, and describe the data, method, and theories that are used.

## **Approach: V2G as a “Niche” in a “Sociotechnical System”**

To help understand the promise and challenges of V2G, the book largely views the related transport and electricity infrastructure connected to V2G as a “sociotechnical system”—looking at more than just the technical aspects of V2G to how it is part of and influences society.

The term sociotechnical system finds its origin rooted in multiple disciplines and approaches. One of the best known is Thomas Hughes’s work on the history of the electric utility system, wherein he argues that the generation, transmission, and distribution of electricity occurs within a technological system that extends beyond the engineering realm [18]. Such a system is understood to include a “seamless web” of considerations that can be categorized as technical, economic or financial, political, environmental, and social, making it “sociotechnical.” Large modern systems integrate these elements into one piece, with system builders striving to “construct or ... force unity from diversity, centralization in the face of pluralism, and coherence from chaos” [19]. If the managers succeed, the system expands and thrives while,



**Fig. 2** A sociotechnical system for personal automobile transportation (Reprinted from [20])

simultaneously, closing itself (both its meaning and set of relationships) for disruption, resistance, and change. In other words, the influence of the outside environment on a sociotechnical system may gradually recede as the system expands its reach to encompass factors that might otherwise alter it.

In other words, the concept of a sociotechnical system helps reveal that technologies, such as electricity grids and V2G, must be understood in their societal context and that the different values expressed by inventors, producers, managers, regulators, and consumers shape technological change all in their own way. System builders, it follows, must overcome a complex milieu of sociotechnical obstacles to reap benefits. A salient insight from the sociotechnical approach is its focus on the interrelationship of linkages between elements and co-evolutionary processes, e.g., that a system never stands on its own but is nested in other equally complex sociotechnical systems. Figure 2 offers an illustration of the sociotechnical system that surrounds modern, conventional, car-based land transport [20].

The book takes a sociotechnical approach, as such an analytical framework encourages scholars to look beyond single dimensions without

**Table 1** Overview of sociotechnical dimensions of a V2G transition

Dimension	Inclusive of	Example(s)
Technical	Technology, infrastructure, and hardware	Vehicle performance, grid interconnection, communication, battery degradation
Financial	Price signals, economics, regulatory tariffs	Capital cost of V2G charging stations, hardware, batteries and interconnectors, revenues, cost savings, business models
Socioenvironmental	Broad social costs and benefits	Mitigated greenhouse gas emissions, air pollution, integration with renewable sources of energy, externalities
Behavioral	Consumer and user perceptions, attitudes, and behavior	Consumer perceptions of all of the above, including benefits, inconvenience, distrust, confusion, range anxiety

losing the complexity of the system and doing injustice to the many interactions and relationships that shape it. Specifically, we investigate V2G across the various sociotechnical categories summarized in Table 1. These include, first, the technical or technological elements such as batteries and charging infrastructure, tires on vehicles, and interconnections to the electricity grid. Next are the financial or economic elements that encompass the cost of the technology as well as the availability of fuel and any affiliated cost savings and revenues that can be generated. A third category is socioenvironmental, and how the technology relates to the overall benefits (or costs) to society. A final category focuses on the individual behavior of consumers and users, namely the owners and operators of EVs that might take part in V2G programs. We see each of these dimensions at play in different parts of our chapters.

In laying out the following chapters below, it is not our intent to suppose that demarcations between “technical,” “financial,” “socioenvironmental,” and “behavioral” dimensions really exist in distinct, separate classes. The entire point of the sociotechnical systems approach is that

such impediments are seamlessly interconnected; dividing the “social” from the “technical,” or even the “economic” from the “environmental” is counterproductive and dangerous, since it misses the point that such factors exist in an interstitial and interdependent network. In other words, it is a heterogeneous combination of sociotechnical factors that determine whether V2G technologies will achieve widespread acceptance or face consumer rejection. Thus, while reading each chapter, the readers are heavily encouraged to consider the seamless connections to other chapters of the book.

Within well-established field of sustainability transitions studies, one particularly strong framework often utilized is that of the multi-level perspective, or MLP [21]. Borrowing from a mix of disciplines, including history, evolutionary economics, institutional theory, and science and technology studies (STS), the approach suggests that diffusion or transitions occur through interactions among three levels: the niche, the regime, and the landscape. The niche refers to a radical innovation that is emerging to gain diffusion or adoption, to move from invention and innovation to viable market introduction [22]. The regime level refers to the incumbent sociotechnical system that the niche is potentially affecting or replacing; such regimes contain cognitive, regulative, and normative institutions [23]. The “landscape” refers to exogenous developments or shocks (e.g., economic crises, demographic changes, wars, ideological change, major environmental disruption like climate change) that create pressures on the regime, which in turn create windows of opportunity for the diffusion of niche-innovations. Figure 3 illustrates how the three scales interact.

A key term of art within the MLP framework is that of a “transition pathway.” Analytically, the claim is that different kinds of interactions among niche, regime, and landscape result in different kinds of alignments. Geels and Schot [24] construct a typology based on combinations between two dimensions: the *timing* and *nature* of multi-level interactions. This leads them to distinguish four transition pathways: (1) *technological substitution*, based on disruptive niche-innovations that are sufficiently developed when landscape pressure occurs, (2) *transformation*, in which landscape pressures stimulate incumbent actors to gradually adjust the regime, when niche-innovations are not sufficiently developed, (3) *reconfiguration*, based on symbiotic niche-innovations