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ASSESSING ELECTROMOBILITY

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Mobility appears to be a distinctive human attribute. Moving ourselves, things and ideas has always been at the heart of human development. During 95% of the two hundred millennia humans have existed, we literally walked the Earth and moved around as hunters and gatherers. Our bodies were designed for long distance walking and running on the savannah and it has been claimed that the most important invention ever was the bag.[1] The one thing that made humans exceptional (apart from our ability to jog) was the ability to communicate, enabling effective cooperation. Lacking physical strength, our early evolutionary advantage was the ability and will to cooperate and share. The bag made it possible to bring home the catch of today and share it with the group.

Similarities in the design of early stone tools found in different geographical areas shows that the long distance transport of goods, the diffusion of ideas and maybe even trade have been around for a long time. The agricultural revolution, the emergence of settled societies and specialisation amplified the volume and importance of trade and transport. As a complement to walking, draught animals were domesticated and placed in front of carriages. Over the centuries, rowing boats and sailing ships opened new pathways for communication and exchange along the waterways of the world. In the 18th century, large sailing ships transported the raw materials and products of the British textile industry, generating capital to be reinvested in the embryonic industrial economy. The invention of the steam engine meant that chemical energy could, for the first time, be transformed into motion beyond the bodies of humans and animals. With coal-fired factories, trains and ships the industrial revolution became a reality. In the 19th century, local and global trade and travel escalated rapidly, changing both power relations between nations and the lives of ordinary people.

1 Berg, L. (2012). Skymningssång i Kalahari. Hur människan bytte tillvaro. (In Swedish). Stockholm, Ordfront förlag.

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Electricity systems were developed in the second part of the 19th century, enabling new communication technologies in the form of telegraphs and telephones; providing light to growing cities and powering short-distance vehicles such as trams. The electrified 'horseless carriage', i.e. the electric car, followed shortly after. However, in the 1920s, internal combustion engine vehicles (ICEVs) drove the elegant electric vehicles (EVs) out of the market. People increasingly wanted to travel beyond towns and Henry Ford's assembly line meant that the Model T fell in price every year. The subsequent coevolution of ICEVs and oil extraction and refining changed the way wars are fought, the way cities are built and the way we arrange our daily lives. In 2010, petroleum oil still accounted for more than 90% of the energy used for transport (Chapter 2).[2]

Meanwhile, electric motors continued to develop and conquered steam engines and internal combustion engines in numerous applications. Batteries, first applied in the telegraph systems of the 19th century, entered an era of massive diffusion towards the end of the 20th century as they coevolved with the electronics industry and the ubiquitous deployment of information and communication technology. Despite the failure of the early electric car, transport technologies were slowly becoming more dependent on electricity. Rail transport underwent a shift from steam and horse to electricity, and during the 20th century various electric subsystems were added to ICEVs, ranging from the electric starter in the 1910s to modern computer-based control and entertainment systems (see Figure 2.3).

In the early 21st century, humanity faces a dilemma. While our demand for mobility and transport continues to increase we are challenging nature's capacity to support this growth. The people now walking the Earth are thousand times more numerous than the hunters and gatherers in pre-agrarian times, and to bring home the catch of today the walks across the savannah have been replaced with commuting by car and intercontinental flights. Oil powered ICEVs deplete limited resources, pollute the cities of the world and contribute to climate change at an increasing pace. The overarching question we pose in this book is whether the continued electrification of mobility – electromobility – can resolve this dilemma.

The book covers a wide range of topics that assess electromobility in different ways. One theme addresses the desirability of electric vehicles and propulsion systems; to what extent they are in some sense better than other options; and what is required to make them better. A second theme is related to the likelihood that electric vehicles and propulsion systems will be adopted; if they can compete with other options; and what is required for them to enter markets, develop and diffuse. These themes can be approached from many angles. While some general methodological considerations are found in Chapter 1 in Systems Perspectives on Biorefineries, we here directly jump to the outline of this book and some tentative conclusions that can be drawn from its chapters.

Chapter 2 provides a definition of the term 'electromobility' and describes some general technical configurations that we consider as important variants of electromobility. This chapter also outlines the main drivers and barriers of electromobility. In Chapter 3, we dive into the electric vehicle in order to get to know its

2 Food used for mobility powered by muscles is not included in this figure.

components and some vehicle configurations. From this micro level starting point we then move out in different directions. In Chapter 4, we stay close to the car and discuss safety aspects. In Chapter 5, we investigate the concept of energy efficiency by first addressing the delicate matter of finding a measure for the energy efficiency of vehicles, and then extending the system boundary to include different ways of converting primary energy sources to electricity and fuel. In Chapter 6, this life-cycle perspective is extended further to include different environmental impacts both in the fuel chain and for vehicle and component production.

Component production does not only result in environmental impacts but also relies on the availability of a range of potentially scarce metals, as discussed in Chapter 7. This highlights that electromobility must be adapted to, but will also adapt global materials systems. The success of electromobility will rely on the coevolution of electric propulsion and a number of different systems. Chapter 8 investigates the dependence on future energy supply systems and analyses competition with other options, such as hydrogen from coal plants with carbon capture and storage and biofuels. Chapter 9 explores the link to the electric power systems and examines whether electric vehicles will enable or complicate the introduction of intermittent renewable energy sources such as solar and wind.

Chapters 10-14 address various issues related to market demand, user preferences and cost. What types of electric vehicles fit current driving patterns (Chapter 10)? Will electromobility shape user preferences or vice versa (Chapter 11)? Does the different performance and cost profile of electric vehicles open up for, or even require, new business models (Chapter 12). Alternatively, are substantial governmental subsidies needed to boost market share and production volumes and help in reaching a level of maturity where competitiveness is ensured and growth is self-sustained (Chapter 13)? While Chapters 10-13 address passenger vehicles, Chapter 14 outlines the perspectives of two different types of freight companies and explores the pros and cons of electric city delivery trucks and electric road systems for long distance transport. While Chapters 12 and 13 investigate firm strategies and governmental policies related to market formation, another key issue for firms, as well as governments, is knowledge production. In the final chapter, Chapter 15, we discuss the challenges for the automotive sector in different countries in gaining access to the knowledge and know-how required to build electric vehicles.

One conclusion that can be made is that EVs are not inherently less safe (Chapter 4), more expensive or more complicated than internal combustion engine vehicles (Chapter 3). However, EVs will require the same amount of knowledge and experience that has accumulated around the ICEV (Chapters 2 and 15) and an adapted infrastructure (Chapters 2, 9 and 10).

A second general conclusion is that the environmental benefits of electromobility will depend on the development of renewable electricity (Chapter 6). If electricity is produced from coal, electric propulsion will mainly lead to problem shifting and substantial greenhouse gas emissions. However, electric propulsion allows us to tap into the vast energy resources provided by the sun (Chapter 5, Figure 5.7b) and could thus enable a sustainable global transport system of current proportions

or larger. This also implies that the many limits related to biofuel systems can be circumvented (see Systems Perspectives on Bioenergy).

However, battery costs and the a high proportion of short distance trips (Chapters 10-13) and batteries' reliance on potentially scarce metals (Chapter 7) with related environmental impacts (Chapter 6) suggests that plug-in hybrids with smaller batteries combined with the possibility to use, for example, biofuels for infrequent longer trips could be a more viable option (Chapters 8 and 10), in spite of the more complex configuration of the vehicle itself (Chapter 3). An alternative, or complement, could be to use cars in new ways, including car pools that provide a range of different vehicles for different purposes (Chapters 2, 11 and 12). In any case, the electric vehicle is unlikely to be the second vehicle of households due to the high investment cost and low running cost (Chapter 11). The problems of a multipurpose vehicle seem to be even larger in the freight sector, where it seems unlikely that any single electric propulsion system can replace the diesel engine in all applications (Chapter 14). On the other hand, the freight sector might offer ideal niches where different electric propulsion systems can find their first economically viable application, such as quiet electric distribution trucks in cities or electric road systems in freight corridors.

It is also evident that the current transport system based on oil and ICEVs, once incubated in the early 20th century, is entrenched, locked-in and rigid in many dimensions ranging from physical infrastructure to knowledge production and the habits of people (Chapters 2, 11, 12 and 15). Breaking this lock-in and enabling electric propulsion to get a foothold will likely require substantial efforts by established firms and entrepreneurs as well as governments at local, national and supranational levels (Chapters 12, 13 and 15). Inventiveness and policy that support market formation will be required together with measures that stimulate knowledge development and diffusion.

In the end, the future of human mobility will be the outcome of countless decisions taken by humans. The full system consequences of these decisions can never be revealed in advance and we will always to some extent be blind to the impact of our actions. However, we believe that some factors can be exposed and understood and thereby subjected to deliberation. We hope that the knowledge, arguments and ideas provided in this ebook can be useful in the process, stimulate fruitful discussions and provide some guidance.