DIGITAL ENERGY TRANSITION: DIFFUSION OF NEW SOCIAL PRACTICES AND THEIR IMPACT ON THE ENERGY SYSTEM

Stermieri Lidia, Paul Scherrer Institut, +41 563104706, lidia.stermieri@psi.ch
Panos Evangelos, Paul Scherrer Institute, +41 56 310 26 75, evangelos.panos@psi.ch

Extended Abstract

1. Overview

Digital transformation implies a continuous process of change, with emergence of new business models, an increase in the use of digital technologies and more prevalence of the internet of things.

The innovation and opportunities introduced by digitalization need to be compatible with the environmental goals and the energy strategy of a country. Information and Communication technologies (ICTs) have the potential to reduce energy consumption, increasing the efficiency of energy processes and substituting physical products with digital products. However, the complexity of ICT system and the variety of impact mechanism make the quantification of the impact of ICT on energy consumption very challenging [1].

To understand the disruption effect of ICTs on energy sectors and their positive or negative effect on energy consumption, the starting point is their diffusion in the households' daily activities (social practices) [2]. New social practices and business are emerging via the diffusion of ICTs and old ones are phased-out. For example, the "home office" practice is increasingly replacing the conventional practice of "commuting". This practice is directly linked to the diffusion of ICTs and it has an indirect effect on transport demand, on energy consumption in the residential sector and services sectors. Several studies apply empirical research to assess the change in social practices due to the integration of ICTs ([3],[4],[5],[6]). However, the assessment of how the social practices will evolve in the future and the quantification of their direct and indirect impacts on the whole energy system has not been performed yet in a consistent and integrated way [7]. This paper describes a new methodology to fill this research gap, by introducing an agent-based model to understand adoption and spread of digital practices in the society, simulating the decision-making process in households and firms. To identify future trends of the digital transition and analyze the related energy implications for the whole energy system of a country, the agent-based model is linked to an energy system model based on the TIMES modelling framework of IEA-ETSAP[8].

The coupled modelling approach is novel and unique in its kind as it is able to analyze the disruption effect of digitalization, underlining the role that new social practices have in shaping the future energy transition while incorporating systemic effects of the entire energy system and providing useful insights for policy makers.

The methodology is applied to the case study of Switzerland, which is ranked 6th in the IMD World Digital Competitiveness in 2020 [9] and where the planned phase out from nuclear energy requires the exploration of sector coupling strategies and a deep understanding of the citizens' role in achieving long-terms energy goals. The methodology can be adapted to other countries as well.

2. Methods

The methodology combines an agent-based model (ABM) to estimate the adoption of social practices by consumers with an energy system model to investigate the interdependence between the digital trend and the country's long-terms energy goals.

2.1.An Agent-Based Model for social practices

The decision-process mechanism of households that lead to the adoption of new social practices related to ICT ([10],[11]) and new emerging business strategies emerging for companies in different sectors can be explored with an ABM.

The agent-based model can be divided in two levels: at the micro-level, agents represent households, while at the macro-level, agents simulate the decision-makers of companies and firms.

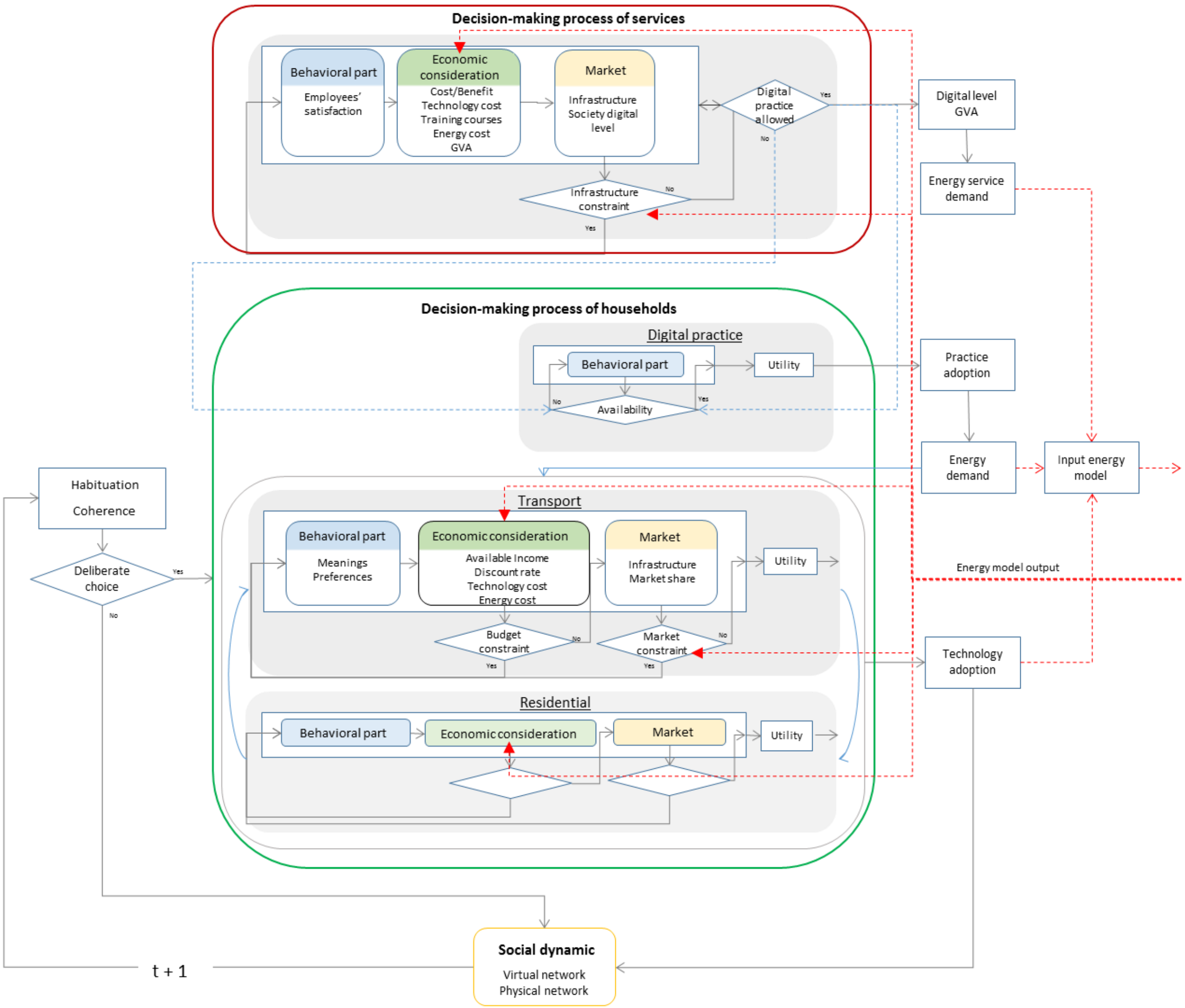

Figure 1. Scheme of decision processes and dependencies between agents in the agent-base model. The red box shows the decision process of services. The output is the digital level, the Gross Value Added (GVA) and the energy demand of the service. The decision process of services is connected with the decision process of households (green box) through the blue dot lines. The output of the decision process of household is the energy demand of transport and residential sector and the share of technology adoption. The output of the ABM (outgoing red dot lines) are input to the energy model. The ongoing red dot lines are the output of the energy model translated into input for the ABM. The energy model gives input for the economic consideration in both decision processes, and affect the market and infrastructure constraints (the evolution of infrastructures is analyzed in the energy model)

At the micro-level, the interactions and the dynamics between households show the emergence of digital trends and the consequent impact on the energy demand for different sectors. The population of agents and their socio-demographic attributes (e.g. income, age, education) are dynamic in time, based on assumed economic and demographic growth.

Following the rational behavior theory, agents choose the practice that maximize their utility, weighting their preference for a certain practice [12] (see Figure 1, behavioral part of the decision process of households), with its related cost/benefit (economic and market considerations in Figure 1). To consider the complexity of information spread in a digital society, the common approach of only developing a physical social network of agents' interactions is not enough. An opinion dynamics model [13] is applied to simulate the interaction and learning process of agents in their social network, which in our approach s subdivided in "virtual network" and "physical network". In the physical network agents interact with agents in their neighborhood, while the virtual network simulates the social media interactions, to explore the role digital technologies have on spreading information. The two networks are characterized by different probabilities of create and destroy links, different thresholds and different learning speed. Through these interactions, agents modify their preference for a practice over time. The adoption of a different practice occurs if the practice currently adopted does not match their preferences or if the current practice is not anymore economic sustainable as consequence to a change in the market price (a budget constraint based on available income forces agents to adopt only practices and technologies that are affordable).

At macro-level, companies and firms consider the input coming from the micro-level as part of their decision process. The well-being of employees and consumers affect their cost/benefit considerations, but at the same time, companies' decisions affect the ability of households in the micro level to perform some practices, in an interdependency process (Figure 1, blue dots lines). Companies evaluate cost and benefit related to the digital practices and decide to adopt the practices that comport a benefit. The emergence of new business related to digital practices allows estimating the current and future level of digitalization of the society. This digital level considers the digital readiness of companies in four relevant thematic areas: processes and infrastructure, digital sales, customer involvement, and people and culture [14]. Each of these areas are ranked from the minimum level 1, where digital technologies and digital practices are not adopted, to a maximum level 4, symbolizing a total digitalization. The adoption of digital practices and the consequent investment in digital technologies increase the digital level of the companies.

Furthermore, the exchange of information between micro and macro level aims to reproduce and simulate one of the disruptive effect of the digital transformation: the decision processes of decision-makers and citizens become more interconnected. The ABM analyzes on an annual basis these micro- and macro-interactions between households and companies, from 2020 to 2050.

2.2.Coupling the ABM with an energy system model

The interdependency between the digital transition is analyzed with the ABM, while the impact on the energy system is assessed through the coupling with the Swiss TIMES energy systems modelling framework (STEM) [15] . STEM minimizes the total energy system cost and provides energy flows, investments on technologies and environmental indicators.

While the ABM is a socio-economic model aiming to analyze the heterogeneity of decision processes and the factors that lead to the adoption of social practices, STEM is a technology rich optimization model. To couple the two models and allow them to share information, technologies in STEM are aggregated into groups according to preselected features (e.g. type of fuels, environmental impact, efficiency). Thanks to this selection, each group is characterized by specific qualities able to match the preference of agents in the ABM. For example, the transport sector is represented by four aggregate technologies: Internal combustion engine vehicle, Electric vehicle, Hybrid vehicle and Bus. Each of these shows a different investment cost, efficiency, fuel type and environmental impact, giving to the agents in ABM the possibility to choose according to their preference (an environmental friendly agent will select the technology with the lowest environmental impact) and their available income. Having the same representation of technologies in both models, they are able to interact.

The coupling is represented in Figure 2: the evolution of the energy demand and households preferences on technologies quantified within the ABM are passed to STEM (blue line).

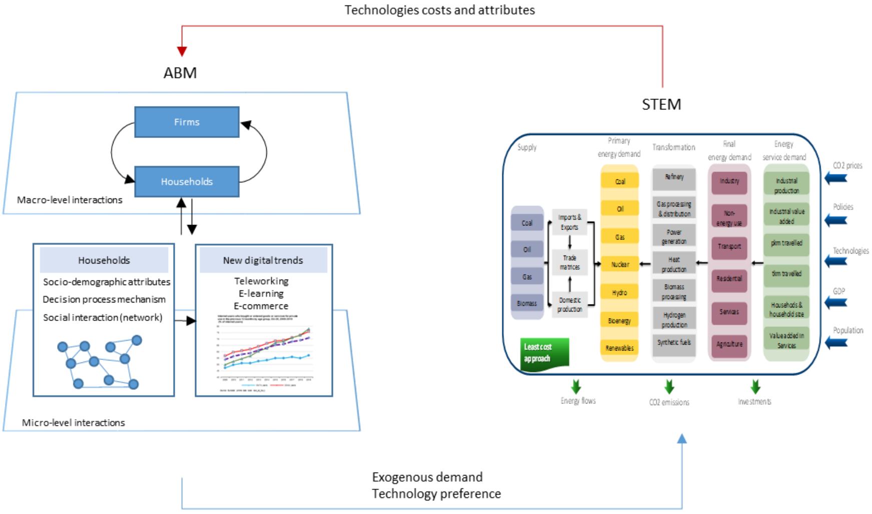

Figure 2: coupling between the ABM and the energy model

The input coming from the aggregate technologies in the ABM is disaggregate to allow STEM to fully use its optimization potential to evaluate the best technology mix for the energy system. After STEM is solved, it aggregates again the output and provides energy and technologies costs as input for the economic part of the decision process of agents in ABM (red line). Due to this aggregation/disaggregation of inputs, the two models iterates until when the convergence criteria is satisfied. On the contrary to what has been done in other studies ([16], [17]), where the overall technology mix is also included in the ABM, our aggregate approach allows us to analyze several sectors in the ABM with a reasonable computational time, encapsulating all the technologies' features that are relevant to assure heterogeneity in the decision process. Furthermore, it reduces the amount of data needed to calibrate and validate the ABM and gives to the energy model more flexibility to operate.

The combined modelling approach allows to quantify the implications arising from the diffusion of new social practices in a digitalized society for the whole energy system and to provide insights for policymakers.

3. Results

To assess the robustness of the methodology and demonstrate it, the digital practice "Teleworking" is analyzed as case study for Switzerland. The methodology previously described is applied to simulate the spread of this practice, to forecast its dynamic and to understand the effect that this digital transformation concerning the working environment will have on the energy sector.

In Switzerland, the employees performing the social practice "Teleworking", enabled by the diffusion of ICTs, increased to 23.8% in 2018 (compared to 6.6% in 2001) [18]. In the ABM, at micro-level, the preference of households for the teleworking practice is initialized with data from the Swiss Federal Office of Energy (SFOE) and the Swiss Household Energy Demand Survey (SHEDS) [19]. At macro-level, companies consider the preference of their employees for teleworking in the decision process: the practice increases the productivity of employees and reduces the absenteeism ([20], [21]), which is translated into an economic benefit for the employer. Companies evaluate cost and benefit related to the digital practice (e.g. the cost for new software and hardware, training courses, the reduction of labor for cleaning, the energy savings [22]) and decide to adopt the practice if it comports a benefit.

To quantify their digital level, the teleworking practice is analyzed under the "people and culture" area, where the degree of digitalization is ranked from 1 ("digitalization hardly concerns the staff") to 4 ("digital skills are considered in the hiring criteria"). Starting from an average digital level of 2 in 2020 for Swiss companies, the model investigate how employees' preferences and economic considerations can lead companies to an upper digital level (the digital level is normalized in figure 4b).

Scenario	***BASE***	***Digital***	***E-world***
Digital society	*• ICT development annual growth rate: 0.28%* *• ICT intensity usage related to social practices:: 30%* *Example: «teleworking»* *30% working hours* *30% online meetings*	*• ICT development annual growth rate: 1.40%* *• ICT intensity usage related to social practices: 60%* *Example: «teleworking»* *60% working hours* *60% online meetings*	*• ICT development annual growth rate: 1.85%* *• ICT intensity usage related to social practices: 100%* *Example: «teleworking»* *100% working hours* *100% online meetings*
Climate target	*0 Mt CO_2 in 2050* *CO2 tax: 336 CHF/t in 2030, 360 CHF/t in 2040, 2917 CHF/t in 205*		

Table 1: Digital scenarios. The ICT intensity usage is related to the social practices. In the example of teleworking, for the base scenario it is assumed that agents performing teleworking will work from home the 30% of their working hours, and the 30% of their meetings will be in the form of online meetings.

Three different scenarios are analyzed, assuming a different rate of diffusion and a different utilization of ICT in the society (Table 1).

In the scenarios analyzed, agents performing teleworking reduce their commuting demand respectively by 30%, 60% and 100% , while their residential demand for heating and electricity increases respectively by 20% and 10% in relations to the number of days of teleworking (these assumptions are made by considering a change in the occupancy pattern of the building whit a consequent impact on the energy consumption [25]).

Preliminary results indicate that the practice of teleworking has a long-term impact on the transport demand (figure 3a) due to the reduction in commuting (-5% in 2050 for digital scenario, -16% for e-world scenario). However, it increases the energy consumption of the residential sector (+4% in 2050 for digital, +6% for e-world, figure 3b). At the same time, the energy demand in services, represented by companies encouraging the teleworking practice for their employees, decreases. An average evolution of the digital level of service sectors is shown in figure 4b, where in 2050 the degree level 3 is reached for the digital and e-world scenarios (the companies provide trainings to develop the digital skills of their staff). The increase of the teleworking practice in future, involving almost 45% of the working population in 2050 for the digital and e-world scenarios (figure 4a), also accentuates the demand for internet data (the practice of video conference is assumed to increase by 2 hours per week, with a data transfer rate of 2 Mbps and an electricity use by the internet infrastructure and data center of 0.42 kWh/GB [23]). This results in additional 2 PJ on the electricity demand for the digital scenario in 2050, and an additional 2.3 PJ for e-world scenario.

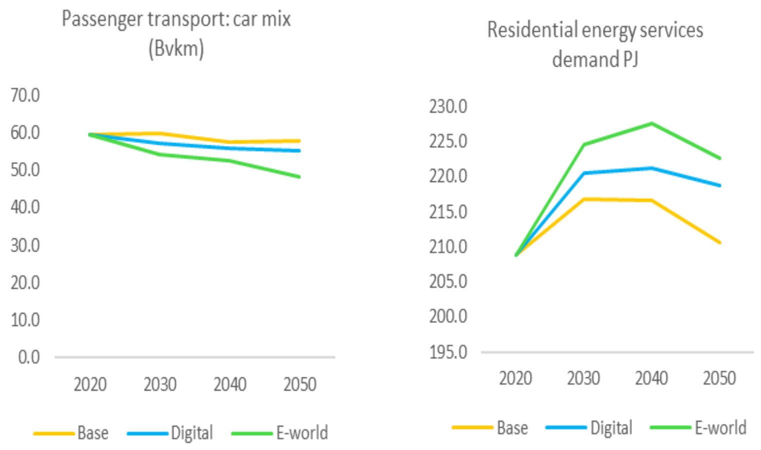

Figure 3a:.Transport demand in Bvkm for the three energy scenarios. Figure 3b. Residential energy demand (PJ)

The impact that the evolution of the social practice “teleworking” has on the energy service demands of the end-use sectors is identified within the ABM and it is passed to STEM to assess implications for the whole energy system of Switzerland. Compared to the base scenario, where the diffusion of ICTs and the related adoption of social practices slightly increases over the time horizon, in the digital and e-world scenarios the implication of the further expansion of “teleworking” leads to an increase of 3% and 7% of the CO_2 emissions in 2040 (Figure 5a), in line with the conclusion of Matthews & Co [24]. This increase in the emissions is mainly connected with the increase in the use of natural gas and a slower phase out from light fuel oil boilers in the residential sector. The energy system reacts to the increase of CO_2 tax in 2050 increasing the use of natural gas heat pumps in 2050 for the digital and e-world scenarios, with a reduction of CO_2 emission from the residential sector of 8% for digital and 14% for e-world compared to base(figure 5b). Although, it is important to underline that these moderate effects on the energy system depend on the assumptions related to the impact on energy consumption of the digital practice. On the contrary, the variation of the occupancy patterns for buildings in the services sector together with new working models arising with this practice (e.g. flexible working space allows a reduction of the office area [26]) decrease the energy consumption of this sector. The different energy demands and technologies’ adoption in residential and transport sector results in a different configuration of the whole energy system, with an increase in the imports of biofuels and a related increase of 1 BCHF/y in 2050 for the e-world scenario compared to the base (figure 6). The rebound effect of the teleworking affects several energy sectors, but in contrast whit what has been done in previous studies, where only one sector at the time is analyzed [27] ,our multi sectoral approach allows considering the interdependencies between different sectors and the reaction of the energy system to these impacts.

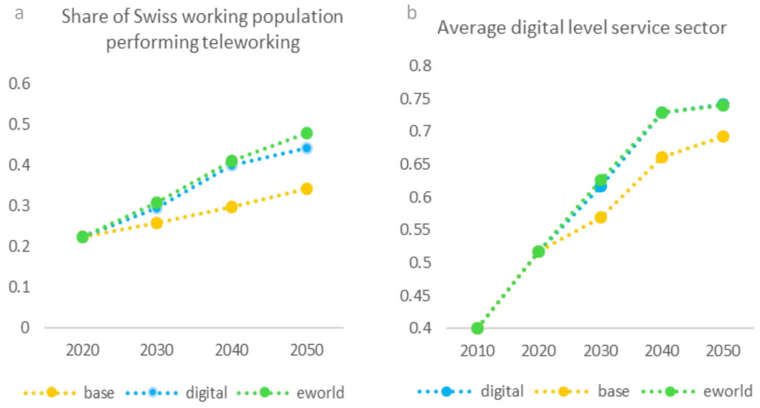

Figure 4a: Evolution of teleworking practice in Switzerland as share of the working population. Figure 4b. Average digital level of service sectors in Switzerland (only the services for which the teleworking practice can be performed are considered)

4. Conclusions

Citizens are now in the center of the energy transition. Empowered by digitalization, they choose the services they need and the way they use energy. They become active players in this new landscape of more connected and efficient energy systems. As new social and business practices are emerging via the diffusion of ICTs and old ones are phased-out, their impact on the energy system is the core of this analysis that brings together societal elements and robust technical-economic energy systems frameworks. The results from the case study underline how our approach is able to answer some outstanding questions about the effects of digital practices on the energy system and in the specific about teleworking [26]. The integration of the two models allows quantifying: how teleworking affect long-term decision making of households; if the practice changes the mode of transportation of adopters; the effect of the practice on the energy consumption of buildings in residential and service sector; the energy demand associated to the related use of ICTs; and the overall implication for the energy system and associated CO_2 emissions.

The energy implications of digital practices must be considered in future energy policies, to promote an efficient way to use them to achieve the decarbonization goals of a country while avoiding their negative effects. The methodology presented in this paper represents an important tool for quantifying and analyzing these implications.

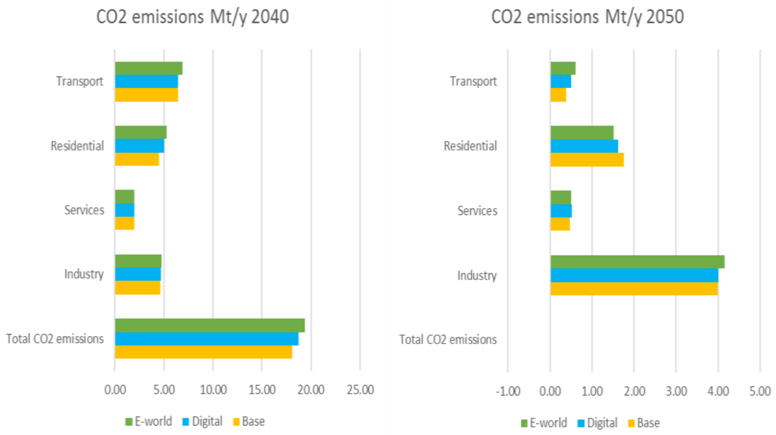

Figure 6a: CO2 Emissions by sectors in 2040, Figure 6b shows the CO2 emissions in 2050, in Mt/y

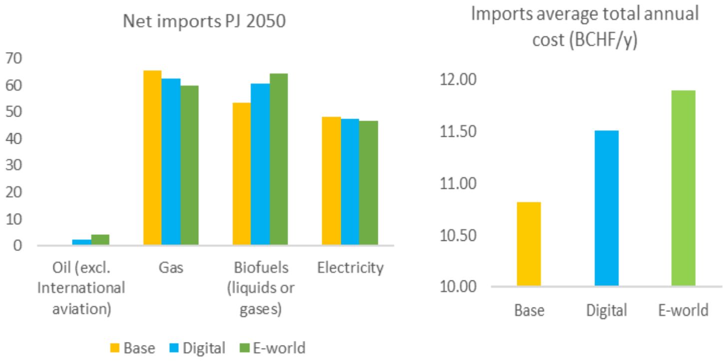

Figure 5a: Net imports (in PJ) for 2050 are shown for different scenarios, Figure 6b. Shows the total annual costs of imports in 2050 (BCHF/y)

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