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Research article

Financing of the global shift to renewable energy and energy efficiency

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Abstract: A global shift to low-carbon economies needs five times larger annual investments in renewable energy and energy efficiency compared to the present USD_{2005} 200 billion. The question about how to finance those large investments is discussed with particular attention to the citizens' savings because they are hardly used so far, except a few countries. If good conditions are created, activation of these savings is sufficiently large and it is rewarding regarding the cost-reducing technological change and many civil initiatives. High international prices of fossil fuels create favorable conditions but they are unpredictable whilst the present policy support for energy business and CO_2 taxes do not compensate for the low prices. High CO_2 taxes could do but meet opposition. Innovations in the USA and EU add value to the energy businesses by USD_{2005} 9.2 billion a year based on average during 2005–2015, which exceeds their R&D on renewable energy and energy efficiency. Innovations in energy business also generate spin-off that exceeds 1% of the global GDP though the spin-off strongly varies across countries. The value addition motivates the supply-oriented and demand-oriented policy support for those energy innovations, in particular subsidies and price guarantees, respectively. Experiences with the subsidies in the USA compared to the price guarantees in the EU show that the latter involved larger expenditures but generated many more new firms and jobs per USD_{2005}. A price guarantee per CO_2 would invoke distributed energy systems entailing higher more energy-efficiency and energy security. Innovations generate adaptations when applied on larger scale. Their cost-reduction is function of scale; the projectable cost-reduction reduces the financial risks. Estimates show that the global investments in wind and solar power are efficiently allocated and operations are cost-effective. In addition to the power generation, those renewable energy with storage technologies deliver co-benefits to the energy producers and consumers and business models emerge tuned to the local conditions. The citizens' participations in energy-efficiency and renewable energy would be enhanced if policies guarantee the annual value of the participants' savings. Such guarantee would generate tax returns due to more companies and higher value of assets. The citizens participation with policy support enables the global shift to sustainable energy.

Keywords: financing; investment; renewable energy; energy efficiency; citizens; savings

JEL Codes: Q56; E60; O11

1. Introduction

Financing of the global shift in energy business towards renewable energy and energy-efficiency is discussed. The energy business, herewith, encompasses exploration and exploitation of energy resources, followed by production of fuels, heat and electricity, and finally distribution, storage and services of energy for consumption in businesses and households. In 2015, it delivered about 14,000 million tons oil equivalent (t.o.e.)[1] for USD 6,400 billion consumer expenditures (Enerdata, 2019), which was nearly 10% of the global Gross Domestic Product (GDP) in constant USD dollars of 2005 year (USD_{2005}). Herewith, large, growing private and public investments in energy-efficiency and renewable energy are financed but even larger investments are necessary for that global shift. This paper discusses a few possibilities to involve citizens in that financing.

Throughout the last two centuries, biomass, hydropower and other traditional renewable resources partially shifted to fossil fuels based on coal, oil, gas and nuclear, which are challenged by modern renewable energy based on wind, solar, geothermal, wave and other energy resources. It is hypothesized that these substitutions decreased density of carbon to hydrogen and electrons in the energy resources which reduced energy consumption per product, referred to as energy-efficiency (Herman et al., 2009). The shifts in energy production were largely driven by the consumer demands of businesses and households; for example, when the production capacity in the United States of America (USA) enlarged from 306 GW in 1850 to more than 35,000 GW in 2000 nearly 90% of that increase is realized outside the energy business because in industries, mobility and in appliances (Grubler, 2012). Given those demands, policies often triggered changes for the public good. For instance, substitution of biomass for coal in USA was driven by policies aiming to prevent deforestation caused by combustion of wood in fireplaces (Rosenberg, 1973 (1977)) and the electricity production expanded in the USA when city authorities enforced the electric city lights because aimed to avoid fires caused by the gas lights (DiLorenzo, 1996). Similar interactions between the consumers demands and policies can generate the shifts to energy-efficiency and renewable energy, for instance demands for energy security with policies on mitigation of climate change.

Consumers' demands triggered modern renewable energy because enabled energy security, it is cleaner energy production and consumption in remote areas on Earth and in Space where traditional energy resources are scarce or unavailable. Despite fluctuating solar and wind energy by day and night, meteorological conditions and other disadvantageous factors, which require energy storage in water, heat, batteries, hydrogen and other media this production emerged in the United States of America (USA), Japan and a few countries in the European Union (EU) in the 1980s (Haas et al., 2011). It is consumed in alternative communities, telecommunication, aerospace, sports, gadgets albeit at high costs. Although opposition of the vested interests was fierce, modern renewable energy grew slowly during 1990–2004 and fast because 11.1% annual average during 2005–2015 to present 1.5% global energy consumption

[1] GW capacity used for 1 hour is 1 GWh (10^3 MWh = 10^6 kWh) which equals 86 ton oil equivalent (t.o.e.) when 1 t.o.e. equals 7.3 barrel oil equivalent (b.o.e.).

that grew 1.8%; as estimated with data of the International Energy Agency (IEA, 2019). Currently, the consumer demands for cleaner, flexible, autonomous energy consumption invoke production off-grid with modern renewable energy and storage, so called distributed energy services. The global off-grid energy consumption grew by 22% measured by the capacity of battery storage (REN, 2017).

Global investments in renewable energy were low until the 1990s because a few billion dollars per year but grew fast during 2000s from USD_{2005} 53 billion in 2005 to USD_{2005} 205 billion in 2015 while the share of wind and solar power increased from 65% to 96% of those investments (BNEF, 2018). Herewith, the share of public financing increased from one quarter in 2005 to 47% in 2015 of all, the share of energy businesses and industries declined from a third to quarter, the private financiers and charity remained 19% and the category 'unclassified' declined from 20% to 13% (Mazzucato and Semaniuk, 2018); the last category refers to energy services in communities and citizens' initiatives. Hence, policies spend more public finances on renewable energy rather than create incentives for more private investments. Such policies need additional taxation for the energy expenditures which compete with health, education sanitation. It also undermines popularity of modern renewable energy because people rarely demand more taxes. Nevertheless, more citizens participation is justifiable because renewable energy and energy efficiency promises nearly infinite energy consumption all over earth on large and small scale, though more space is needed, as well as reduction of USD 5,200 billion damage costs per year caused by carbon emissions and other pollution from the energy business as estimated by the International Monetary Fund (Coady, 2015).

Changing policies are needed with regard to even larger global investment for mitigation of climate change. The global shift toward sustainable energy by 2050 would need about 1,085 billion yearly investments, nearly fivefold of the present ones. Although these investments enlarge global income and employment, and improve environmental qualities entailing lower damage costs their financing is risky because returns on investment are uncertain and present assets can be lost (IRENA, 2018). Based on the World Bank data, those investments would capture about 2% of the total global capital formation, if the past growth is assumed, compared to nearly 1% in 2015. That large capital capture cannot be achieved with more public financing alone because of competition with other public needs. Additional private financing must be found. This paper seeks the financing possibilities through the citizens' involvement; this option is often neglected in the authoritative reports for policymaking (e.g. de Jager et al., 2011). The financing based on the citizens' savings is addressed because citizens hold large savings in banks and have a say in the pension funds, cooperative insurances and other institutional financiers that compound the citizens' savings into funds. The global household savings are estimated by the International Monetary Fund to approach 8.9% of the disposable income that is gross income minus taxes (Grigoly et al., 2014). Based on available data about the disposable income, these citizens' savings are about USD 3504 billion a year in the OECD countries, i.e. high income countries[2]. The global savings are larger because include the savings in mid and low-income countries which are presumably lower per citizen but grow fast. Hence, the scale of savings is sufficient to cover a large part of those investment but how to activate these savings for renewable energy and energy-efficiency is a question.

Large citizens' participation in renewable energy and energy efficiency is achieved in some countries; for instance, citizens in Germany possessed 47% of all renewable energy assets in 2015.

[2] The disposable income in OECD was USD 31,000 per person (OECD, 2019a) for 1.27 billion people (OECD, 2019b) and 8.9% saving in it, global disposable income is not found; the estimate is 31000*1.27*8.9/100.

That large share of all assets in renewable energy is largely based on small but numerous investments because many citizens are involved in local civic organisations (Yildiz, 2013). In addition to Germany that has a long-standing tradition of communal energy more countries experience and pursue suchlike citizen's participations though citizens efforts in the participation are needed and the implementation is supported by policies (Sovacool, 2016; Interreg, 2018). Those participations enrich the conventional financial models for the bankable projects (debt-based) and shareholding in ventures (equity-based) with new models of the financing of renewable energy, such as crowdfunding and social ventures (Tyl and Lizarralde, 2017). The implementation of such models, however, requires policy support given that about 80% of financiers and project developers prefer the conventional models for large scale projects; this result is based on an inquiry among a few hundred financiers and project developers (Oji et al., 2016). Hence, policy support is needed for the citizens' participation and a few possibilities for activating citizens savings are discussed in this paper.

In this paper, innovations and cost-reducing adaptations of them in energy services to consumers in businesses and households are addressed, whereas the processing of resources into heat and power are neglected because rarely tangible to the consumers except when pursued in the consumption. With reference to Schumpeter's "doing things differently" ((1935) 1989) innovations are comprehended as novel technologies in businesses and adaptations as incremental improvements in their performance. Herewith, research and development of novelties are costly and they are risky to innovators because profitable sales after production are uncertain whilst know-how has low commercial value unless possessed at a cost as saleable patent, trademark, or another attribute of ownership. An additional risk of the financiers is that they are less knowledgeable about the novelties than innovators who have interest in promoting qualities without disclosing all deficiencies known to them. This asymmetric information between the innovators and financiers is widespread. It is observed even among so called ethical investors and innovators who are considered to be trustful; as a result of that information asymmetry only a few out of hundred ethical innovators are financed by the ethical investors and most innovators ask for policy support which is easier to get (Krozer, 2015a).

A successful sale of an energy innovation adds value to an innovator's activities whilst the successful sales of several energy innovations during subsequent years are expressed as the growing value added per year in the energy business, referred to as the valorization of energy services. The sales can be successful if the purchasers generate benefits after subtracting all costs; these benefits can be the cost-reducing energy consumption and the positive effects of that consumption on productivity and welfare because these positive effects can disseminate across various businesses and households outside the energy business. The value added in economy due to the positive external effects of the innovations in energy business are referred to as a spin-off; not to confuse with spin-out of vested firm. The spin-off is indicated by the value addition in economy per energy unit. High valorization and large spin-off indicate opportunities for financiers because high returns on investment can be expected.

The discussion about the citizens' participation is based on the World Bank data about the energy demands and on the data of International Energy Agency (IEA) about the energy supplies. Appendix 1 shows key indicators: The Gross Domestic Product in Purchasing Price Parity (GDP-PPP), it is GDP corrected for inflation based on the country's prices for a typical consumer baskets, energy and electricity consumption, as well as the shares of all renewable energy and modern renewable energy in the global energy consumption. They refer to the year 2015 and annual average growth during years from 1990 to 2015, which are divided into the period 1990–2004 when the international oil prices were low and policy support of renewable energy was low aside a few countries and the period 2005–2015 when those prices and support were high. The latter period indicates favourable conditions for energy efficiency and renewable energy. All growth rates are annual average during those periods. The World and 14 countries above 100 million inhabitants are shown; the European Union of 28 members (EU) considered as if one country. In ascending order of GDP-PPP, these countries are: the USA, Japan and EU—called high income, followed by the Russian Federation (Russia), Mexico, Brazil, China, Indonesia, Philippines and India—called mid income, and Nigeria, Pakistan, Bangladesh and Ethiopia—called low-income. Together they covered in 2015 about 70% of the global population, 74% of the global GDP-PPP, 65% of global energy production, 72% of energy consumption, 76% of electricity consumption, as well as 88% of coal supplies, 63% of oil, 64% of gas, 83% of nuclear energy, 71% of biofuels, 66% of hydropower, 84% of modern renewable energy and 73% of the global CO_2 emissions.

After this introduction, the international prices of fossil fuels and subsidies are discussed (section 2), then possibilities to reduce the risks of participations in the energy business (section 3) followed by possibilities to attract the citizens savings in energy projects (section 4), and finally conclusions are drafted.

2. **Market scale**

High prices of fossil fuel resources render alternatives cheaper, thereby more attractive for energy services. Hence, high prices of fossil fuels in international energy markets invoke investments in energy-efficiency and renewable energy, which in turn attract the financing of those investments. Hence, this financing evolves within framework of the international energy market that can hardly be influenced by individual financiers and businesses, unless they act collectively toward a common goal. The impacts of price changes are uncertain. Higher international prices of fossil fuels can invoke energy-efficiency and renewable energy but also trigger investments in cheaper coal and search for domestic, cheaper alternatives, for example tar sand and shale gas. An additional uncertainty is that the prices fluctuate periodically because of unbalanced supplies and demands, cyclic production overcapacity and events that impede supplies or enlarge demands, such as price agreements and demands booms, respectively. These fluctuations are rarely foreseeable because need collaborative actions of various, often opposing interests but a slow downward trend of the resource prices throughout the last century is estimated when correction of these prices for the fluctuations and inflation (Shafiee and Topal, 2010). Within the downward trend, the prices swing between USD 150–250 per t.o.e. during low prices, it is when they are assumed to approximate the market equilibrium, and between USD 600–800 per t.o.e. from 1979 to 1986 and from 2005 to 2015 when they were considered exceptionally high due to those unforeseen events; the unforeseen events were agreements between the oil producing countries and exceptional demand growth, respectively (Morriss and Meiners, 2016). The price increase was USD_{2005} 400–500 per t.o.e.

Another general trend is that the energy consumption grows slower than the purchasing power due to changes towards less energy-intensive activities and more energy-efficiency. High prices of fossil fuels enhance energy-efficiency but large differences across countries are observed. In high income countries, where the purchase power grew slowly throughout 1990–2015, the energy consumption per capita increased a few percent slower than the purchase power in the period of low oil prices but during high prices the purchase power hardly grew whilst energy consumption decreased by 1.5% to 2.8% a year. In most mid and low-income countries, where the purchase power grew fast throughout 1990–2015, the energy consumption grew 1%–2% below the purchase power during low fuel prices and 3%–4% during high fuel prices. The energy consumption and purchase power in those countries are not very sensitive to the international prices of energy resources presumably because the domestic energy prices are heavily subsidized but their economic structure shift towards less energy-intensive activities, in particular from industries to services; the energy consumption in Brazil increased and hardly changed in China during high prices.

The growth of purchase power during high energy prices invokes usually more renewable energy but the impacts differ across countries and it varies with respect to the traditional versus modern renewable energy. The share of all renewable energy in energy consumption varied from 3% in Russia to 94% in Ethiopia in 2015, nearly all being the traditional renewable energy. While the share was low in high income countries and hardly grew during low prices but it grew much and increased from 4% to 7% of all energy consumption during high prices. In most mid and low-income countries, however, the share was much higher but decreased during low and high fuel prices. Different trends are observed with respect to modern renewable energy whose share grew fast in several countries throughout the period 1990–2015, even by 20% to 40% annual average in China, India and Brazil. The fuel prices hardly mattered in these countries. High prices did invoke faster growth of modern renewable energy in high income countries, particularly in the EU. However, modern renewable energy hardly grew or even decreased in other mid and low-income countries. Globally, the share of all renewable energy hardly changed whilst the share of modern renewable energy increased fast.

Compared to those price fluctuations on the international energy market the policies instruments had only a modest influence on the domestic energy prices. The IEA data show that the global policy support for energy was USD 728 billion at the top in 2011 and decreased to USD 409 billion in 2015, about 84% of that support was for fossil fuels (IEA/OECD 2019). The total support was certainly much larger because not all countries are covered, neither all energy resources per country nor all support per resource. If the EU support is used as a global indicator, which is an approximation because the EU member countries encompass high and mid income countries, its support by USD 178 billion in 2015 escalated with its GDP of USD 16,416 billion in the global GDP of USD 74,819 billion indicates that globally the total policy support for the energy business has been larger than USD 810 billion in 2015. Even this twice larger estimate of policy support compared to IEA/OECD data is incomplete because important tax exemptions in the EU are not covered in subsidies and subsidies for consumer prices in low-income countries are largely neglected though they are substantial and nearly all directed in support of fossil fuels. Given 13,790 million t.o.e. global energy consumption in 2015, the policy support based on the EU escalation was solely USD_{2005} 59 per t.o.e. compared to USD_{2005} 400–500 per t.o.e. above the equilibrium prices. In addition, a few countries introduced taxes on CO_2 emissions. Given 2.53 ton CO_2 per t.o.e. (IEA, 2017), the highest market price per ton CO_2 was about USD_{2005} 198 per ton CO_2 (USD 500/2.53) compared to the Swedish tax of USD 139 per ton CO_2, Swiss tax USD 101 per ton CO_2 and Finnish one USD 79 per ton CO_2 in 2015; other taxes were lower (Keen et al, 2019). The International Monetary Fund recommends the CO_2 tax of USD 30–70 per ton depending on the countries' economic situation and emission reduction targets (Lagarde and Gaspar, 2019). Hence, the policy support together with the highest CO_2 tax is lower than the price increase during disequilibria on the international energy markets. Policies could have enhanced energy-efficiency and renewable energy in a few countries, particularly in the high income ones, but hardly globally.

The growing purchase power of citizens triggers energy-efficiency and modern renewable energy in few countries whilst high international prices of fossil fuels enhance that incentive; the incentive is stronger than policy support of renewable energy and CO_2 taxes. However, the growing purchase power and high fuel prices cause limited impacts in many countries compared to the aim of sustainable energy. Hence, focused, smart' support for energy-efficiency and renewable energy is needed along with reduction of subsidies that impede changes; herewith, 'smart' refers to incentives for innovations and adaptations discussed in the next sections.

3. Innovations in energy business

As mentioned in the introduction, innovations in the energy businesses add value to the innovating firms and to the users of those innovations; the values added generated in various business across economy due to the innovations is called spin-off. Such positive external effect of innovations in energy business on a whole economy is indicated by the GDP per energy consumption, referred to as energy-intensity (WEC, 2019). For example, the spin-off of refining energy resources into fuels and electricity production during 1900s invoked larger energy production in industry, increased productivity in manufacturing and welfare in households because enabled larger pressures, fine mechanic, faster motion, better ventilation, more light, stronger sound and many others capabilities in firms and households. From 2000s on, the purchases of wind and solar power with storage enabled non-polluting, flexible energy consumption off-grid which fostered innovative activities as aerospace, electric mobility, telecommunication, consumer products and distributed energy services though the off-grid consumption is costlier than on-grid.

Within the energy businesses, the valorization of energy services at households during high prices of fossil fuel during 2005–2015 was annual average of 2.0% in the USA and 2.8% in the EU. This value growth was mainly driven by modern renewable energy. The value growth put together is equivalent of additional USD_{2005} 9.2 billion per year, which is fivefold of their financing of research, development and demonstration in energy efficiency and renewable energy. Hence, opportunities to increase value in energy services is an incentive for the innovative efforts in the USA and EU. Although precise data for other countries is not found the valorization of energy services across countries is indicated by 0.7% to 5.6% higher growth of the electricity consumption than energy consumption from 1990 to 2015 (Krozer, 2019). The spin-off is even larger. The spin-off is estimated as additional value during subsequent years formally:

$$V_t = \sum_t^n \left[\left(\frac{GDP_{t+1}}{E_{t+1}} - \frac{GDP_{t1}}{E_{t1}}\right) \cdot GDP_t\right] / t \qquad (1)$$

where V_t is average value addition and E_t is energy consumption.

Based on the World Bank data, it is estimate that the global value grew by 1.7% throughout 1990–2015, it is equivalent of USD_{2005} 376 billion a year. This spin-off is about 35% of the envisaged investment for the sustainable energy, which is a reasonable return on investment. Investments in energy innovations can be profitable from perspective of the national economic development. About 0.8% value is added to the global GDP during that time; it is 0.1% to 1.6% across countries with exception of Brazil where the value decreased. Relatively valuable energy business in GDP is found in in Japan, EU, China, Indonesia, Philippines and India but less in other countries. The spin-off was low during low fuel prices and much larger during high prices which implies than higher resource prices invoke innovations that contribute to the national income; in that period renewable energy and storage in batteries expanded. These findings indicate that the financing of innovations in energy businesses is attractive during high prices in the countries mentioned above because high spin-off is generated but less attractive during low prices and in other countries where the spin-off is low. The spin-off per country throughout 1990–2015, as well as during low and high fuel prices is shown in Appendix 2.

The spin-off justifies policy support for the innovative energy business. A relevant question, herewith, is about what kind of policy support can generate large spin-off. That policy support can be supply-oriented or demand-oriented. The supply-oriented policy support is based on assessments of innovative proposal and selection of the most promising ones. This kind of support is specific because addresses a particular innovator that can obtain a subsidy, tax exemption or another kind of support; more than two hundred of this kind of instruments for innovations are found (Ermen, 2007). The demand-oriented support refers to the support of demanded goods which can be delivered by all suppliers, for instance support for a minimum energy price. This support is generic because applies to all suppliers; more than a dozen of suchlike policy instruments are found (Krozer, 2015b). The generic support is generally larger than the specific one.

During high fuel prices, the USA support of renewable energy was mainly supply-oriented with subsidies and tax exemptions for specific projects, whilst the EU was mainly demand-oriented based on the price guarantees per unit of renewable energy that is delivered to grid, so called feed-in tariffs. The former was covered by the public expenditures, the latter was covered by business because enforced as obligatory fee to be paid by all network operators; tough, a few EU member countries paid from the state budget. Note that the USA has larger subsidies for research and development than the EU but excluded from this assessment because the specifications for energy are not found. The impacts of those approaches on the energy business differ. They are indicated by the number of new establishments because indicate innovators; establishments are mentioned rather than firms because a firm can have several establishments. The costs of policy support for renewable energy per establishment is assessed based on IEA data. The lowest costs per new establishment indicate the cost-effective instruments. The period 2008–2015 is covered, which means the period during high fuel prices after the financial crisis because earlier data about that support are not found. As expected, the total specific support for renewable energy in the US was smaller than the total generic support in the EU.

Table 1 presents all establishments, establishments in energy business and the additional ones in that business the USA and EU, as well as the policy support in the current USD per additional establishment; jobs are also estimated but not shown. The USA policy support with subsidies to the energy services was average USD 0.12 per kWh. The USA had yearly average of 13,200 energy establishments, 0.12% of all establishments, and about 100 new ones with 600 jobs are generated. The subsidies were about USD 30,320 average per additional establishment. Despite those subsidies the number of establishments even decreased during a few years despite as indicated by the negative number. In EU, the policy support mainly with price guarantees was average USD 0.40 per kWh, which is about threefold of the USA. The EU had 118,000 energy establishments, 0.5% of all, and 15,000 new ones were added with 1300 jobs; this is manifold more new establishments. This support was about USD 5880 per additional establishment on average which is one fifth of the USA support. The EU policies largely based on price guarantees delivered larger support to energy businesses than in the USA and generated many more new establishments and jobs. The EU support

Table 1. Comparison public support of new energy firms in the United States and European Union.

In 1000 establishments	2008	2009	2010	2011	2012	2013	2014	2015	Average
United States: mainly subsidies (*)									
All establishments	7601	7433	7397	7354	7432	7432	7563	7664	7484
Support in USD per kWh	0.14	0.16	0.17	0.15	0.14	0.10	0.08	0.06	0.12
Energy establishments	12.1	12.4	12.8	12.8	12.9	13.1	13.1	13.2	13
Additional establishments		0.3	0.3	0.1	0.1	0.2	0.0	0.1	0.1
Additional support per additional establishment		22,612	18,668	7,875	6,205	−23,465	261,318	−80,972	30,320
European Union: mainly price guarantees (**)									
All establishments	23,940	24,358	24,387	24,747	24,976	24,899	25,436	26,278	24,878
Support in USD per kWh	0.47	0.46	0.43	0.40	0.34	0.36	0.38	0.32	0.4
Energy establishments	58	75	96	114	139	148	149	164	118
Additional establishments		17	21	18	24	10	1	15	15
Additional support per additional establishment		477	344	846	26	2,797	37,335	−662	5,880

Note: (*) EIA data (**) Eurostat data, euro converted into USD based on the World Bank conversion data.

Those findings have a few implications for the financing of renewable energy and energy efficiency. First one is that renewable energy adds value in the energy business and in economies which generates high return on investment, but the returns are not necessarily accrued by the innovator in energy business but outside that business. Second, large spin-off of innovations in renewable energy justifies policies in support of innovators rather than protection of the vested interests. Third, the price guarantees for renewable energy are cost-effective policy instruments for those innovations. A price guarantee per CO_2 emission reduction is an attractive policy instrument in support of energy-efficiency and distributed energy services in communities, which reduce dependency on grid and defer costly large-scale energy infrastructure.

4. Adaptations in energy projects

Innovations perform rarely perfectly when launched but entail many adaptations which improve the performance and reduce costs in time when they are repetitively applied. Hence, innovations disseminate in regions where conditions for the repetitive applications are made suitable. Note that the conditions are not primarily related to natural environment because determined by regional social capabilities and interests with help of policies. For instance, the photovoltaics technologies (PV) for solar power did not expand in sunny Arab countries but in cloudy Germany, particularly in Freiburg due to social interests and local policy. Similarly, windmill farms did not enlarge in windy southern Argentina but in milder Denmark and Spain, in particular in the Navarra region (Spain) due to its regional policy. Investments in applications, therefore, are usually concentrated spatially, and their financing is driven by collaborative actions of regional stakeholders and politics, which generate regional specializations (Krozer, 2012). The adaptations of innovations due to repetitive applications enable to reduce costs per energy unit in time, referred to as the cost-reduction technological change or technological learning.

The technological learning evolves as a pattern described by the decreasing unit cost function of scale of the applications (Doyne Farmer and Lafond, 2016); this holds true solely for the repetitive applications of products because the unit costs of production technologies cannot easily be described (Krozer, 2008). The unit costs of renewable energy are projectable based on the scale of applications; for instance, the cost projections of several renewable energy technologies mid 1980s were reasonably precise twenty years later though the scale of applications was smaller (McVeigh et al., 1999). Estimates of the technological learning in energy business show that the unit costs of modern renewable energy decrease faster than the unit costs of fossil fuels and traditional renewable energy, whilst the nuclear power becomes costlier (Rubin et al., 2015), but there is large spread in the cost data which suggests that other factors than scale are also important. Since these costs are projectable the investors' risks can be reduced by sound assessments of the technological learning. The decreasing unit costs can be driven by lower costs in manufacturing equipment and by lower costs or better performance in operations with equipment; the former is often called "learning by doing", the latter "learning by using".

The technological learning is illustrated in Table 3. It shows the global investments in applications of wind and solar energy in USD_{2005} billion, realized capacities in Tera Watt (TW) and unit costs per capacity in USD_{2005} per kW, which indicate learning by doing. Furthermore, the production costs of power in USD_{2005} per kWh are shown based on the international comparison of winning tenders (Lazard's, 2019), which indicates the technological learning. A remark, herewith, is that the unit costs of wind and solar power vary across countries and databases (Unit costs, 2019). The data for 2015 and average changes during 2009–2015 is shown; earlier data is unavailable. The investments in wind and solar energy, which covered 96% of all investments in all renewable energy in 2015, grew by 18% and 29%, respectively, while the capacity grew much faster, which indicates effective investments. Along with larger capacity the costs per unit of capacity of wind power and solar power decreased by −5% and −12%, respectively, which confirms the theory. The costs per unit produced wind power and solar power decreased even faster because 13% and 24%, respectively, which indicates efficient operations. It means half lower unit costs of energy production in 5 and 3 years, respectively. In 2015, these unit costs approached the unit costs of power generation with fossil fuel and the spread between highest and lowest unit costs of renewable energy decreased. These applications became cheaper due to less costly installations (learning by doing) and thanks to more cost-effective operations (learning by using). The returns on investments became also more predictable.

Table 2. Cost reducing technological change: applications of wind and solar power.

Global data, change from 2009 to 2015	Investment (*)		Capacity (**)		Unit cost capacity		Cost-effectiveness (***)	
	2015 USD$_{2005}$ billion	change %	2015 TW	change %	2015 USD$_{2005}$ /kW	change %	2015 USD$_{2005}$ /kWh	Change %
Wind energy	101.9	18%	838	23%	0.12	−5%	0.055 ± 0.046	−13%
PV Crystalline	146.5	29%	256	49%	0.57	−12%	0.044 ± 0.014	−24%

Note: (*) BNEF data, (**) IEA data, (***) Lazard's average and spread.

In addition to the decreasing costs of modern renewable energy benefits can be generated. A checklist of benefits based on literature is shown in Appendix 3. They refer to the individual and collective interests of producers and consumers. For example, the spread of financial risks is relevant for the individual producers whilst less price volatility, deferred infrastructure and reuse of polluted areas contribute to the producers' collective interest. The individual consumers can gain energy security and noise reduction whilst communities generate tax income and jobs due to more firms and less pollution. However, only one quantification of those benefits is found (Adamec et al., 2011) though a broad set of costs and benefits is more often considered in the financial assessment, labelled as the social return on investment (Krlev et al., 2013). New business models for the life cycle of installations emerge. Table 3 shows a number of alternatives for the financing of projects. One can find the supply-oriented business models focus on particular technologies (e.g. a heater for household), agreements on technology improvements in time (e.g. replacement for better heaters), and partnerships in supplies (e.g. development of heat-balance). Alternatively, the demand-oriented business models address service performances (e.g. yearly air conditioning), agreed improvements, (e.g. annual energy reduction), and co-operative performance (e.g. district heating); the demand-oriented business models are often referred to as the energy service companies or ESCO's (Bertoldi and Boza-Kiss, 2017).

Table 3. Business model for renewable energy and energy-efficiency.

Supplier\Customer	Performance targets	Upgrading operations	Cooperation
Supply-oriented	Supply with merit points for specs, e.g. for low carbon	Innovations vouchers, e.g. seed money for upgradations	Partnerships in the implementation process
Demand-oriented	Agreed performance of energy services (ESCO's)	Certificates, for the continues energy improvement	Citizens co-operatives e.g. trusts in communities

Given that the cost-reducing technological change of modern renewable energy is better forecastable the financial risks decrease in time as novel technologies disseminate, which enables citizens' participation in the investments when the returns on investments above interest on bank savings are ascertained. However, the activating of bank savings is challenging because the individual savings are usually small, vary in time and across citizens whilst crowdfunding is laborious for the repetitive investment and rarely sufficiently the large-scale, costly projects. The activating of bank savings needs guarantees from authorities. Such guarantees are feasible when the energy services guarantee high performance because develop specializations due to a continuous stream of projects. This can be enforced with certification. State-of-art certification are kept up to date with seed-money for know-how in businesses, called innovations vouchers. This way, citizens gain reliable suppliers, energy services generate markets and communities can accrue benefits, such as tax income.

5. Conclusions

A global shift to sustainable energy needs about fivefold larger annual investment in renewable energy and energy-efficiency than the present USD_{2005} 200 billion average a year. The citizens' participation is addressed because their savings are large financial resources whilst their financial involvement is low aside a few countries, and it decreases compared to the stakes of public authorities. Mainly statistical data is used for the period 1990–2015 divided into 1990–2004 when conditions are unfavorable because fuel prices and policy support were low and 2005–2015 when the prices and support were higher. The data cover fourteen largest countries by population divided into high, mid and low incomes, EU 28 as if one country, and the world.

Possibilities for the financing these investments are assessed with regard to fluctuations of the international prices of fossil fuels. An observation is that high prices generated stronger incentives for renewable energy and energy-efficiency than the policy incentives even if subsidies and high taxes on CO_2 are combined though these taxes are actually close to nil in nearly all countries. High international prices triggered global increase of energy-efficiency by a few percent a year and invoked growth of modern renewable energy by 11% annual average but also divergence across countries is observed; several fast-growing countries by income hardly increased energy-efficiency and low-income countries hardly enlarged renewable energy. Shift of subsidies for fuels into subsidies for energy efficiency and taxation of CO_2 during low fuel prices would foster income growth and prudent energy consumption.

Innovations in the energy business add value to the energy services and economies as a whole. The value added of energy services in the USA an EU grew by 2% to 2.8% per year during 2005–2015, respectively, which is larger annual equivalent in value than their annual expenditures on research and development of renewable energy and energy efficiency. These innovations also generated spin-off which enlarged the global GDP by USD_{2005} 370 billion a year. Several high income and mid income countries increased their GDP by more than 1% a year but low-income countries performed poorly. Comparison of subsidies for renewable energy in the USA to price guarantees with feed-in tariffs in the EU shows that the latter were costlier per energy unit but several times cheaper per innovation measured by number of new firms and jobs. The feed-in is a cost-effective policy instrument for innovations. The price guarantees per unit CO_2 would encourage off-grid solutions for heat and power with energy storage, which would foster energy-efficiency and energy security.

Innovations in renewable energy generate cost-reducing adaptations when new technologies are repetitively applied because suppliers reach specializations in the manufacturing of equipment and consumers in businesses and households improve operations. Larger scale of applications renders better predictable cost-reduction. Empirical data for the period 2009–2015 indicates that the financing of larger capacity in wind and solar power was efficiently allocated and the energy production was cost-effective entailing unit costs that rival fossil fuels. Next to energy, these applications also deliver co-benefits to businesses and citizens and various business models are pursued to improve energy services. Lower and better predictable costs enable larger citizens' participation in the financing of renewable energy and energy-efficiency. Herewith, the citizens' savings can be activated when local authorities' guarantee the value of bank savings. Such guarantee also generates continuity in operations for suppliers and tax income for authorities. Larger citizens' participation creates finances for leapfrogging in renewable energy and energy-efficiency for mitigation of climate change.

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Conflict of interests

This original paper is delivered for publication in Green Financing and the author possesses the Copyrights.

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