https://doi.org/10.21122/1029-7448-2020-63-4-312-327

UDC 330.3; 339.1

Sustainable Energy Transitions: Overcoming Negative Externalities

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Abstract. Nowadays the world energy system faces numerous transitions and shifts of the existing socio-technical regimes towards higher sustainability. Along with it, the sustainable transitions are often being postponed, slowed down or rejected to avoid negative externalities that could threaten the system stability. In this study, we aim to reach the deeper understanding of the externalities of energy transitions and the vulnerability of energy systems under the influence of negative externalities caused by sustainable energy transitions. Using the Externality theory (Baumol, Oates), Sociotechnical transition theory (Geels), as well as Energy sustainability Trilemma Method for the evaluation of the sustainability of energy systems we argue that such externalities need to be treated (internalized, avoided) by special policy measures other than common (classical) ways which may cause slowing down of sustainability transitions and make extra barriers for them. Transitions to more clean and low-carbon energy systems using energy technologies such as solar, wind, small hydro, biomass, waste management, e-vehicles are in the scope of this paper. It classifies the wide range of policy methods (classical and new) being applied separately and simultaneously, and analyses their application in energy policies designing aimed to combat negative externalities of energy sustainability transitions worldwide, so they might be minimized by properly tailored energy policy in each particular case.

Keywords: energy policy, sustainability transition, negative externalities of sustainability transitions, renewables

For citation: Pysmenna U. Ye., Trypolska G. S. (2020) Sustainable Energy Transitions: Overcoming Negative Externalities. *Energetika. Proc. CIS Higher Educ. Inst. and Power Eng. Assoc.* 63 (4), 312–327. https://doi.org/10.21122/1029-7448-2020-63-4-312-327

Устойчивые энергетические трансформации: нивелирование негативных экстерналий

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Реферат. В настоящее время мировая энергетическая система сталкивается с многочисленными переходами и сдвигами существующих социально-технических режимов в сторону

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повышения устойчивости. Наряду с этим такие устойчивые трансформации часто откладываются, замедляются или отклоняются, чтобы избежать негативных внешних факторов, которые могут угрожать стабильности системы. Авторы статьи постарались донести более глубокое понимание внешних эффектов (экстерналий) энергетических трансформаций и уязвимости энергетических систем под воздействием негативных внешних факторов, вызванных устойчивыми энергетическими трансформациями. Используя теорию экстерналий (Баумоль, Оутс), теорию социотехнических трансформаций Гилса, а также метод трилеммы энергетической устойчивости для оценки устойчивости энергетических систем, можно утверждать, что такие внешние эффекты должны быть подвержены специальным мерам энергетической политики, отличным от общепринятых (классических) способов, которые могут привести к замедлению устойчивых трансформаций в энергетике и создать для них дополнительные барьеры. Рассмотрен переход к более чистым и низкоуглеродным энергетическим системам, использующим такие энергетические технологии, как солнечная энергия, энергия ветра, малая гидроэнергетика, биомасса, утилизация отходов, электронные транспортные средства. Проведена классификация широкого спектра методов политики (классических и новых), применяемых по отдельности и одновременно, выполнен анализ их использования при разработке энергетической политики, направленной на борьбу с негативными побочными эффектами трансформаций на пути к энергетической устойчивости во всем мире, которые можно минимизировать с помощью надлежащим образом разработанной энергетической политики каждой страны.

Ключевые слова: энергетическая политика, устойчивая трансформация, негативные экстерналии устойчивых трансформаций, возобновляемые источники энергии

Для цитирования: Письменная, У. Е. Устойчивые энергетические трансформации: нивелирование негативных экстерналий / У. Е. Письменная, Г. С. Трипольская // *Энергетика. Изв. высш. учеб. заведений и энерг. объединений СНГ*. 2020. Т. 63, № 4. С. 312–327. https://doi.org/10.21122/1029-7448-2020-63-4-312-327

Introduction

Today societies witness the so-called quiet energy [r]evolution, when renewables "quietly" replace conventional energy sources, and numerous cities, regions and countries seriously consider transition towards 100 % renewable energy (RE) supply. Over the past ten years about 553 GW of new renewable energy sources (RES) capacities were installed globally [1]. Leading international banks (Bank of America, Citigroup, Morgan Stanley, Wells Fargo) announced the termination of financing for projects of the so-called grey power generation and industry based on coal [2]. Both developed and developing countries elaborate scenarios of transition toward 100 % RES energy supply in the medium and long run. These countries include Belgium, Sweden, Denmark, Croatia, Macedonia, North Africa, the UK, Germany, Hungary, Poland, the EU in general, Australia, USA and Canada, a group of countries in South America, Israel, India, Philippines, Morocco and others. Now Ukraine examines the possibilities of reaching 100 % RES by 2050. In Dec 2016, the EU presented Clean Energy Package, which presumes at least 50 % of energy from RES by 2030. The main elements of the energy [r]evolution are the introduction of RES through decentralized energy systems that reduce the load on the network and network losses, decommissioning of outdated and "dirty" environmental technologies and decoupling, i. e. differentiation of economic growth and increased use of fossil fuels.

The 100 % RES shift induces numerous challenges to the existing industries, people, ecosystems and so on. In some cases, emerging challenges are being omitted or addressed in unsustainable manner. Contemporary narrative and science consider fossil fuels as those generating negative rather than positive externalities [3, 4]. Being full supporters of transition towards 100 % RE supply, nonetheless, we observe negative externalities of RES as well. Understanding the nature of negative externalities, applicable to RES, brings us to the necessity to address the emerging challenges of negative externalities in order to minimize their negative impact. Generally, all technologies have their pros and cons, but avoiding or at least minimizing the negative externalities of sustainable energy technologies leads to their faster expansion and to more sustainable energy and economy.

In this paper, we analyze policy methods which deal with negative externalities based on their origin and impact: local or global, classical and new, internalizing and technological. Despite similar processes occur worldwide, some externalities affect local communities or ecosystems, whereas global externalities are broad-based, affect countries' economies, being broader than just particular technology negative side. Some of them are inevitable, being related to the very nature of technology, whereas other negative externalities are related to improper ways of doing business or poorly tailored regulatory policy. Understanding of technology performance bottlenecks is essential for improvement of regulatory policy, faster spread of RES, cost-cutting and more sustainable economy.

This paper is structured as follows. Section "Sustainability as a path to minimize negative externalities" focuses on the existing theories and analytical framework. Section "Results and discussion. Practice of dealing with negative externalities of sustainability transitions (NEST)" sees the concept of sustainability as one of ways to minimize negative externalities; reviews several cases of negative externalities in Ukraine and globally and proposes new ways to deal and to cope with the mentioned negative externalities. These cases include improper application of feed-in-tariff (FIT), charging of e-vehicles (EV) in day time, cases of hydro power plants (HPP) with dams, externalities of intermittent RES, i. e. of wind and solar power plants (WPP and SPP), as well as negative externalities of the first generation biofuels.

Materials and methods

Researchers usually distinguish three kinds of externalities which follow the different processes in economy. They are:

a) positive externalities of supply and demand side, i. e. caused by sustainability transitions [5–9];

b) "network externalities" of existing sociotechnical regimes (the technology attractiveness rises with the rate of its adoption), which strengthen the barriers of the existing regimes [10–12];

c) negative externalities of production or consumption thoroughly studied within the Externality theory and Environmental Economics [13–15].

P. Zeppini looks at sustainable transitions as the adoption of a new technology under the influence of social interactions and network externalities. He argues that the technological progress in the form of endogenous learning curves is a fundamental factor of sustainable transitions. He also proposes the sustainable transitions model based on discrete choice dynamics, bounded rationality and switching behavior, and by means of the model he studies the efficacy of different policy measures, e. g. FIT and pollution taxation [9].

A. Owen outlines the necessity of the reassessment and internalization of damage costs resulting from combustion of fossil fuels to obtain their real cost compared to the costs of renewable technologies [12].

Negative externalities of production or consumption in the form of reducible but not totally avoidable ecological impact are the most common among other kinds of externalities discussed by economists, ecologists and other social scientists. They see the problem of externalities in proper allocation (Pigou [16], Coase [17]), internalization (Baumol, Oates [13]), monetization (Keppler [18]) and, if could not be eliminated, in the reduction to an appropriate level (Peter, Bird [19]; Coase [17]). Externalities as the market failure occur because of the absence of the "market feedback" between the "victim" and "generator" of an externality. Arrow [20], Kneese [21] spoke about "the markets of externalities" three decades before the appearance of GNG emissions trading system and white certificates mechanism.

Obviously, the negative externalities of sustainability transitions (NEST) could be studied as a kind of common externalities of production or consumption, but treating (internalizing, avoiding) them only in common ways often causes slowing down of sustainability transitions and makes new barriers for them. Classical methods to treat negative externalities are known as Pigouvian taxation, standardization and quotation, Coasian property rights establishment, FIT.

The development and practical application of new policy methods of dealing with NEST is the matter of importance when speaking about the management of sustainability transitions. Among such methods are:

1) externalities markets arrangement;

2) supplementary markets arrangement;

3) markets redesign;

4) broader economic assessment and reassessment (e. g. system value (SV) together with LCOE);

5) parallel technologies deployment;

6) improved operating strategies (6), i. e. Smart Grid, demand side management (DSM), advanced forecasting and enhanced scheduling of power plants; and some other.

Perhaps, the increasing variable renewables generation (VRE) deployment in power systems is the case with the huge NEST (system security concerns) and with the widest range of policy methods, classical and new. They are:

– classical: the responsibility of VRE operators for non-balances;

– new: energy markets redesign (very close to real-time, the enhancing of interconnections to other systems); supplementary (capacity) markets arrangement and the upgrade of traditional power plants to be able to respond to more rapid supply-demand unbalances; new economic reassessment, parallel technologies deployment (energy storages and the interplay with other energy generation, notably with natural gas), Smart Grid development, and DSM (rising the number of prosumers and their role in supply-demand balancing).

An energy policy designing envisages both simultaneous and separate application of such policy methods, taking into account possible cooperation of some socio-technical regimes (e. g. renewable and nuclear, renewable and gas peak-load etc.) and commitments under the international agreements (climate, environmental, political cooperation). Next sections will provide the analysis and the examples of their implementation.

Sustainability as a path to minimize negative externalities

An energy sustainability transition is such energy transition, which leads to the overall rise effect within the energy sustainability Trilemma {energy security; energy affordability; ecological sustainability} [22]. If an energy transition performance maintains the rise along all three axes of Trilemma and the negative externalities are overcome by positive ones in a way that the overall effect grows, that is an energy sustainability transition [23]. Basing on the Externality theory (Baumol, Oates [13]) and Sociotechnical transition theory (Geels, Schot [24]), the social benefit of a transition could be described as:

$$\mathrm{SB}_T = \mathrm{SD}_0 - \mathrm{NE}_T, \tag{1}$$

where SD_0 – social damage caused by the replaced sociotechnical regime; NE_T – negative externality of a transition.

Marginal social benefit of a transition could be described as the following:

$$\mathrm{MSB}_T = \frac{d\mathrm{SD}_0}{dQ} - \frac{d\mathrm{NE}_T}{dQ}, \tag{2}$$

where Q – volume of demand/consumption (for energy sustainability transition – volume of energy demand/consumption: tons of oil equivalent, MW·h, etc., for e-vehicles: p-km (passenger-kilometre) or t-km (tonne-kilometre)).

If $\mathrm{MSB}_T > 0$, then such transition could be marked as a sustainability transition.

The equation (2) reflects the different influence of externalities at the different levels of demand or consumption. For example, the growing number of fast charging e-vehicles could affect the grid; it demonstrates that the growth of NEST caused by the growing demand is non-linear. The other example is VRE ratio in a power system. Integrating over the first few percentage points of VRE into the power system poses increasing technical and economic externalities, with the increasing disposal of flexibility stock which is available in traditional power systems and the increasing part of such stock is used to integrate VRE [25].

Fig. 1 demonstrates in terms of the Externality theory the sustainable transition from sociotechnical regime (technology) S_0 to S_T. The social benefit of the transition equals to the avoided social damage of the previous regime (technology), diminished by NEST.

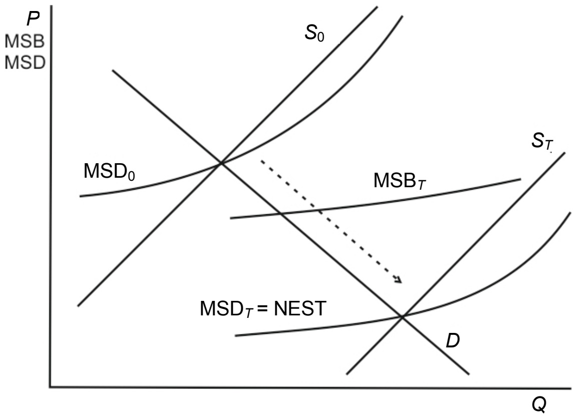

Fig. 1. Marginal social benefit of a sustainable transition: S_0, S_T – supply curves of previous and new sociotechnical regimes (technologies); *D* – demand curve; MSD_0 – marginal social damage (negative externality) of a previous sociotechnical regime (technology); MSD_T – marginal social damage (negative externality) of a transition; MSB_T – marginal social benefit of a transition

Negative externalities are considered to be the cost of resources used by the technology but that are not paid on a market price [26]. Based on that, we can divide policy methods dealing with NEST into two groups:

a) internalizing – methods which are aimed to internalize NEST and to cover their cost by the market prices (1, 4 and classical methods);

b) technological – methods which are aimed to minimize or avoid NEST technologically (2, 3, 5, 6, 7).

The main principle of a policy is that the applied methods should not slow down or postpone sustainability transitions, but force them.

Simultaneous application of internalizing and technological methods could be more efficient compared to the application of the methods of one type only. In the above mentioned example of VRE ratio in a power system both types of methods are usually applied: the responsibility of VRE operators for non-balances, economic reassessment (internalizing) and parallel technologies deployment and supplementary markets arrangement, market redesign (technological).

Results and discussion. Practice of dealing with negative externalities of sustainability transitions

Negative externalities now require detailed attention and brief classification based on types of externalities mentioned in the previous section. Examples of global and negative externalities resulting in poor management might be as follows.

In Ukraine, burning of unsorted wastes to produce electricity and sell it against FIT was suggested. It is a doubtful decision from ecological point of view. In Ukraine, wastes are not being sorted and recycled. The problem scale is so immense, that wastes have already lead to several human deaths in 2016, when four workers of Lviv municipal solid waste landfill tragically passed away while conducting daily operations at the mentioned landfill. This incident has brought attention to the problem of 6700 official and 30000 unofficial overflow landfills all over the country, but has not yet brought Ukraine to the sorting of wastes and further recycling. In Ukraine, 96 % of the wastes is being buried on landfills without further processing. Instead, burning of unsorted wastes to obtain electricity was suggested. We consider this case as unsustainable waste management and improper application of FIT mechanism. The existing solid waste landfills produce methane, which leads to numerous cases of spontaneous combustion. Thus, removal of biogas and further output of electricity, sold against FIT, is a good option for the existing landfills, and maximally possible sorting of wastes with further recycling could be a good option for the upcoming wastes. This could be done by creation of proper regulatory policy toward development of conditions stimulating sorting and further processing of wastes, starting with development and implementation of uniform rules regarding collection and sorting of municipal solid wastes, lack of which now makes impossible investments in wastes recycling plants.

Charging of e-vehicles with fast-charge mostly in daytime creates additional load in the energy system. Even in many developed countries, the existing energy generating capacity is not sufficient to meet the demand for electricity for the vast majority of electric vehicles during the hours of minimum power system load. There are studies indicating that in the US generating capacity is enough to transfer only 70 % of the fleet to electric vehicles. The situation in Ukraine is somewhat different. The coefficient of unevenness of the load curve has recently reached 0.76. The difference between the maximum and minimum daily load in the Ukrainian power system is about 5.5 GW, and the difference between the average daily and minimum load is 2.5 GW. With an average annual passenger car running 20 thousand km, the average daily mileage is 54 km. For simplicity, we suppose that a fully charged battery of an electric car with a capacity of 24 kW·h is sufficient for a run of 160 km and needs to be recharged twice a week for six hours with power consumption when recharging 4 kW. Transition of 10 % of owners of cars (700 thousand cars) to electric cars will entail additional load of the power system during hours of night failure to about 0.9 GW. Consequently, an increase in the transition to electric vehicles to 50 % of owners will positively affect the alignment of the schedule of electrical loads in the power system. However, having more that 50 % of all vehicles as e-vehicles without optimization of energy consumption in the power system of Ukraine (general and electric vehicles), without increasing the value of basic energy generation, without modernization and the transition of electrical networks to European standards would harm the existing energy system. The decrease in the daily unevenness of the load of the power system in the last decade is accomplished by applying economic methods of managing consumers' demand for electric power and capacity or forming economic conditions in which consumers benefit from adjusting their own power consumption regimes.

In Ukraine, where the wide-scale transition toward interval metering has started only recently, charging of e-vehicles with fast-chargers may result in additional difficulties for energy system, as consumers generally prefer fast charging [25]. This scenario is quite possible also because of distribution of chargers that are located mostly in large cities, where people reside mostly in multi-apartment buildings and park their vehicles not in parking lots or garages, but just outdoors, thus having no technical possibility to install individual chargers and where there is quite limited technical possibilities to charge e-vehicles at the long chargers. In other words, in-home charging overnight in Ukraine is limited and will remain limited in future, thus presently faster chargers remain an option, unless legislator would intervene with proper legislation, and market will react with both slower and faster chargers. To avoid charging of e-vehicles during peak hours, many countries have elaborated penalties for using electricity during peak hours, at the same time making non-peak charging more attractive [26–28]. In Ukraine, this kind of legislation is not developed and enforced yet, which creates room for electricity overuse in peak times to charge EVs. At the stage of e-vehicles development some conventional gasoline stations cooperate with e-vehicles importers, offering free charge at gasoline stations even during the day time. Thus, charging e-vehicles only in daytime without proper market regulation makes the practice of e-vehicles charging unsustainable, presenting a negative externality of EVs. There are numerous studies showing consumers' behavior related to charging their EVs. Studies for the USA, Denmark markets [29] state that fast charging itself makes minimal real impact to the grid [30] when the number of e-vehicles is small [31], but it might affect the grid with the anticipated growth of number of e-vehicles on the road. Wilson [32], Christ [33] emphasize that if charging of e-vehicle requires energy obtained from carbon intensive fuel, there might not be saving of CO_2 emissions compared to the vehicle using fossil fuel. In countries where coal dominates in the energy mix, CO_2 emissions from e-vehicles are up to 4 times higher than in countries where electricity is produced from low carbon sources [32]. Even in regions where baseload coverage is relatively low-carbon, charging of e-vehicles during peak times derives from energy generation that can be more carbon intensive, for example, from coal or natural gas. Therefore, the e-vehicles offer rather displaced emission than zero CO_2 emissions, because electricity output from non-RES cause "traditional" emissions.

Examples of local negative externalities might be as follows.

Small hydro power plants (SHPP) are considered as renewable energy source, in some cases providing energy to remote communities that do not have access to centralized energy supply, cleaning small rivers and sometimes fulfilling other important tasks. For instance in Ukraine, Mlynivska SHPP, having capacity of only 0.36 MW, backs up Rivne nuclear power plant in supplying water to cool the reactors [28].

Environmental risks of hydro power plants, derived from construction of dams. Small hydropower plants cause fragmentation of ecosystems, impair the quality of water and affect the hydrology of rivers and their basins. Losses of ecosystems from small HPPs hundreds of times exceed losses from large

HPPs per 1 MW of generated electricity. Simultaneous construction of cascade of SHPPs is often done without considering their cumulative effect. Hydro power plants affect fisheries: during the spawning and migration time the baby fish cannot pass through the dam and die in the turbines. SHPPs cannot contribute significantly to GHG mitigation, because while HPP construction, a water reservoir is needed, and eventually water reservoirs with decaying plants emit methane, which's greenhouse potential is about 25 times higher than that of CO_2. Methane is also dangerous for people working on the rivers, tourists, fishermen etc. These water reservoirs create favorable conditions for mosquitoes way beyond their naturally acceptable population. To start running of HPP, electricity is needed, and it is usually of fossil nature [34]. Despite large HPP and pump storage plants in Ukraine and globally serve as maneuver capacities, water discharge might affect environment adversely, for instance, there is accumulated sludge that needs to be disposed. Water discharge also affects water supply of cities, fields irrigation etc. [28].

Large power plants require dislocation of population where water reservoirs are planned to be constructed. People living nearby become vulnerable to potential floods or other natural catastrophic events, as well as more vulnerable to terroristic attacks related to damaging of dams.

Due to turbines, river beds might be dried, rivers are shallow, which destructs the local ecosystem. In the future, this problem might become more acute even for larger rivers due to process, related to climate change: nowadays in summer flows of rivers all across the Central Europe, including Ukraine, are decreasing, and rivers are becoming shallow. Ukraine already belongs to the group of countries with limited supplies of water, in terms of water being the poorest country in Europe. Reduction of rainfall leads to significant increase of demand for water, more frequent and severe droughts (which currently occur every 100 years). According to forecasts, they will be twice as likely to 2070 in case of reduction of river drain basin [35]. Changing the modes of operation of the cascades of Dnipro rivers' reservoirs will affect the operation of SHPPs, but will not help against water shortages [36]. In Northern Ukraine, annual runoff may increase by 15–25 %, i. e. winter runoff is expected to increase, while spring runoff will decrease, which would also affect the operation of SHPPs. In South and South-East Ukraine annual river flow may decrease by 30–50 %, which increases the risk of droughts and extreme floods [37]. SHPPs adversely affect float types of tourism, as tourists cannot plan their routes through the dams.

To avoid some of the mentioned negative externalities, scientists have elaborated damless power plants; however, they are small and able to provide electricity only to several households. Also, some countries regulate that feed-in-tariff can be obtained only for surplus energy, i.e. energy that is above the needs of local communities (e. g. in Latvia). However, SHPPs often provide higher damage to ecosystem without being able to supply enough energy to meet local community's needs.

Solar power has its negative environmental impact as well. Nowadays there are at least several arguments that need further attention: extraction of silicon from silica requires significant amounts of energy that derives from fossil fuels. Solar power plants require land surface, which creates competition for land with other aspects of land use. Jacobson et al. [38] developed scenarios to achieve 100 % RES in 139 countries, including Ukraine, so that all the energy needs (transportation, heating/cooling, industry, agriculture) would be met only by RES. According to the authors' estimations, this scenario would require 42.54 % less energy than under the BAU scenario due to higher efficiency of energy conversion to work, no need for extraction, transportation or processing fossil fuel, and because the efficiency of final energy use is higher than under the BAU scenario. To ensure the needed energy output, additional area is required, however, the competition for land would not be severe [39] (Tab. 1).

Table 1

Energy generating facilities and area required to fully meet the energy demand in 139 countries globally in 2050[1)]

Technology	Capacity of 1 plant/device, MW	Percentage of 2050 load that would be covered by the plant	Capacity of the plants, GW	Number of new plants, needed for 139 countries	Percentage of territory in 139 countries, needed for new plants[2)]	Percentage of territory as distance between RES objects to locate new plants
Onshore WPP	5	23.52	8332	1582345	0.00002	0.92380
Offshore WPP	5	13.62	4688	935150	0.00001	0.54600
Wave and tidal	0.75	0.58	307	409517	0.00018	0.00860
Geothermal	100	0.67	96	839	0.00023	0
HPP	1300	4	1058	0	0	0
Tidal turbines	1	0.06	31	30050	0.00001	0.00009
Rooftop SPP of households	0.005	14.89	9277	1841306023	0.04026	0
Rooftop SPP of public and commercial sectors	0.1	11.58	7586	74981706	0.03279	0
SPP	50	21.36	12629	251230	0.12832	0
Municipal heliostations	100	9.72	2153	21485	0.05270	0
Total		100	46157	1919518345	0.255	1.478
To cover peak loads and to store energy						
Additional heliostations	100	5.83	1292	12921	0.032	0
Heliothermal power plants	50		4639	84448	0.005	0
Heothermal heat	50		70	0	0	0
Total			**52159**	**1919615713**	**0.291**	**1.478**

[1)] Total area of 139 countries is 119.651.632 km^2.

[2)] Physical area on the surface of ground or water (without area of underground facilities, which makes sense in case of geothermal combined heat and power plants).

The source is [39].

Tab. 1 shows that authors do not expect construction of new HPPs, however, the efficiency of the existing dams is going to be increased. The existing SPP also will be replaced by the more efficient ones, as large SPP can be located only in a few countries. At the same time, the existing buildings' surfaces can be used more efficiently, so that new areas would be used scarcely to accommodate new additional SPP. New RES facilities would require 0.22 % of the total area of 139 countries. The additional area is mainly needed for industrial SPP. Authors do not include areas that would become vacant in future and now are used for the existing, fossil fuels-based energy generation (mining, transportation, processing) and growing feedstock even for biofuels.

The optimal way to diminish this negative effect is to use all possible surfaces that can no longer be used for anything else, such as buildings' rooftops etc. Large solar power plants might negatively impact birds migration, as flying birds consider burning hot surfaces of SPP as water and burn themselves. In future, there will be a growing problem of utilization of used solar panels. Solar thermal or concentrated solar power applications use fluids that absorb and collect heat, being potentially dangerous when spilled.

Generally wind power have gain significant acceptance of society [39, 40]. Ecologists claim that wind turbines negatively affect birds' migration and birds' lives, but there are some other negative externalities. In this extent, a concept "Not in my backyard" has emerged. This concept was even measured: according to Dröes, Koster [41], existing wind turbines had adverse effect on house prices in the Netherlands. Authors witnessed an average 1.4 % price decrease for houses located less than 2 km near the existing turbine. If turbine is located 500–750 m close to the house, its price drops by 2.3 %. Noticeably prices begin to decline three years prior to turbine put into operation (after such plans are declared). On first glance, 1.4–2.3 % does not seem high; however, authors translate it into loss of EUR 3,500–5,600 per house. Turbines, located in urban areas, impose some other constraints, such as noise, vibration, shadowing of nearby properties and change views of landscapes (any of this side effect cannot be directly monetized). This is not only the case of the Netherlands; similar story is observed in the UK (Gibbons [42]), where house prices are about 5 % lower close to wind turbine. Ladenburg, Dubgaard [43] indicate that people in Denmark agree to pay annually to extend the distance of a single wind turbine or wind farm from residential area. These cases indicate that there is a strong need for careful planning of where turbines can be located, which cannot always be presumed by the existing policy. Policy itself might have flaws: Markandya [4] states that FITs are usually developed in the way that there is no difference in FIT size in location of wind turbines. In Ukraine, this particular bottleneck at this particular stage of market development has not arisen yet: now the windiest sites are getting occupied for wind parks, whereas individual turbines are being erected not only in sites where connection to the centralized energy supply is remote (and thus more expensive), but also based on individual preferences and possibilities of a turbine owner. But this might become an issue in future.

The first generation biofuels is one of the most controversial energy sources in terms of assessed energy return on investments (EROI) [44, 45] and their numerous negative externalities. Subsidizing biofuels has led to increased output of feedstock for their production, leading to increased use of nitrates in agriculture [4]. Extensive use of palm oil for the needs of cosmetics and food output has created high demand for this feedstock. Biofuels demand has aggravated the problem. High demand for bioenergy crops of the first generation biofuels led to deforestation of territories in the Amazon River basin. European ambitious target of 10 % of energy from RES in transport sector led to tremendous increase of feedstock use for biofuels globally. This target also brings the question of needed arable lands beyond the territories of where biofuels is going to be consumed. In the EU, the arable land decreased from 120 million ha in 1993 to 109 million ha in 2009 due to consolidation of farms and growing cities [45]. Growing demand for biofuels crops has affected prices of many agricultural commodities, and dilemma "food versus fuel" emerged. Increased use of biofuels has also affected Ukraine, despite the fact that biofuel output in Ukraine almost ceased in 2015–2016 [47], Ukraine is seen as a place to grow feedstock for biofuels for other consumers. It is considered to be a country with plenty of unused land, that "retired" after the Soviet Union collapse, and that this land should be used to grow feedstock for biofuels [48]. Estimations of unused land area vary considerably – from 0.6 million ha up to 4 million ha [49].

Schaffartzik et al. [46] forecast continued supply of feedstock for biofuels production in the EU. For example, rapeseed from Ukraine was expected to continue to be exported to the EU (but in much smaller quantities than a decade ago). Although EU regulatory policy regarding the use of biofuels is gradually changing in favor of the production of the latter according to the principles of sustainable development and from non-edible raw materials, Ukraine still faces phenomena related to indirect land use change (ILUC). Growing and export of rapeseed was significantly growing since 2004, and only within 4 years (by 2008) it increased 20 times. Now rapeseed exports decreased by one third compared to 2014. As of 2010, ILUC caused by the use of biofuel in Europe, was about 5 million ha. By that time in Russia, Ukraine and Kazakhstan there were 23 million hectares of unused land which European companies have started using to plant biofuels crops. In Ukraine, the average use of the land is 0.7 ha/person[1], and, for comparison, in France it is 0.3 ha/person; in Germany it is 0.1 ha/person [46]. However, in some countries rapeseed is grown not on the unused lands. Moreover, in numerous cases in land is leased for growing rape, which causes extreme exhaustion of soil as this is a technical crop, without further restoration of soil. There are some other practices that do not comply with the European sustainability criteria for cultivation of feedstock, and also harm the surrounding farms.

The biofuels policy has already significantly affected Ukraine and expectedly will affect the country in the future (not even talking into account country's international obligations regarding RES in total primary energy supply, output and use of biofuels in the domestic market). Fischer et al. [50] forecast that by 2030 solely for biofuels output 44.2–53.1 million ha of arable land would be

[1] Since 2014 this ratio is different due to loss of territories and population in Southern and Eastern Ukraine.

needed globally, of which 21.8–22.6 million ha would be located in Ukraine. This makes a half of agricultural land in Ukraine and almost 2/3 of arable land in this country. Increased production of feedstock for biofuels will highly compete with production of other types of crops, and will also require a doubling of yields of traditional and new crops, which now represents a significant difficulty. European biofuels policy and technologies undergoes alterations toward sustainability. However, only feedstock types are going to change, whereas both political and market prerequisites would promote cultivation and export of new species of feedstock from Ukraine to the EU [51]. Thus, the production and use of biofuels carries significant direct impact on land use.

The above mentioned externalities are summarized in Tab. 2.

Table 2

Relevant negative externalities of sustainability transitions and ways to overcome them

Case	Policy method to cope with it	(I)nternalizing / (T)echnological
Improper application of FIT	Classical, supplementary markets arrangement	I
Charging of EVs in day time	Broader economic assessment and reassessment, parallel technologies deployment	T
SHPPs with dams	Parallel technologies deployment	T
Solar power	Externalities markets arrangement, supplementary markets arrangement, markets redesign, broader economic assessment and reassessment	
Wind power	Parallel technologies deployment, improved operating strategies	
1st generation biofuels	Classical, markets redesign	I
The source: developed by the authors.		

CONCLUSION

Sustainability transitions, including transitions towards renewable energy sources, may have their negative externalities, and there are ways to overcome them. These externalities might be minimized by properly tailored policy in each particular case. The mentioned negative externalities of sustainable transitions are of supranational nature, but in some cases, they might affect not only countries that employ RES, but also the poorest developing countries (for instance, by affecting food prices). Cases observed bring us to conclusion that majority of negative externalities are similar for many countries globally. Countries may want to develop their own set of measures to handle and minimize negative externalities, but also to use common international experience in dealing with negative externalities of sustainable transitions.

List of abbreviations

NEST – negative externalities of sustainable transitions;
RES – renewable energy sources;
ILUC – indirect land use change;
RE – renewable energy;
FIT – feed-in tariff;
EV – electric vehicles;
HPP – hydro power plant;
SHPP – small hydro power plant;
WPP – wind power plant; SPP – solar power plant;
BAU – business as usual;
SV – system value;
LCOE – levelized cost of electricity;
DSM – demand side management;
EROI – energy return on investments.

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Received: 26 September 2019 Accepted: 4 February 2020 Published online: 30 July 2020