Economic Assessment of Low-Emission Development Scenarios for Ukraine

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Key messages

- Maintaining the current highly inefficient energy system is more expensive than a transition towards a high renewables share in the energy mix.
- Under the current energy policy set up there is an inconsistency between targets of different strategic energy documents (e.g. Energy Strategy, Low-carbon Development Strategy etc.).
- A number of additional incentives should be implemented in order to enable efficient market transformation: measures towards efficient pricing of fossil fuels, in particular price signals for industrial users, more transparent and market-oriented approach to residential consumers, elimination of cross subsidization in the electricity sector, move to competitive energy markets (in particular, fully implement the Third Energy Package), as well as proceed with further integration to the ENTSO-E.
- A successful coupling of TIMES-Ukraine and Ukrainian general equilibrium model helped to identify double dividends (economic and environmental) of the policies under consideration.

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1 Introduction

Global environmental pressure on the Earth System has overpassed safe operating boundaries on many directions (Steffen et al. 2015). One of such dimensions includes climate change, with both advanced and transition economies facing challenges with low-emission development (LED) and the fossil fuels depletion. And while transition economies often face much more severe environmental pressure than the developed countries, they have better opportunities for energy efficiency improvements and emissions reduction with potential for “double dividend” effects (Parry and Bento 2000). Ukraine is a good candidate for such a case. According to the International Energy Agency (IEA 2017), it has 6th highest GDP carbon intensity in the world and its energy intensity is 2.6 times higher than the OECD average. Significant opportunities for technological and environmental improvements are coupled with inefficient market regulatory framework and a poor investment environment.

In recent years, the Ukrainian government has implemented a number of initiatives in energy sector transformation, energy efficiency improvements and renewable energy development, which serve as a good starting point, but are not stringent enough to put the country on the LED path. In particular, the National Renewable Energy Action Plan up to 2020 (CMU 2014), sets an 11% target share for renewable energy (RE) sources in GFEC by 2020. As a comparison, the share of RE in GFEC was 3.9% in 2009 (CMU 2014). Ukraine’s nationally determined contribution (NDC) states that it will not exceed 60% of 1990 GHG emissions level in 2030 (GOU 2015), which is still 40% higher than the 2012 emission level. While Ukraine’s NDC indicates that this target will be revised after the restoration of country’s territorial integrity and approval of post-2020 economic strategies, climate change experts consider current goal as a “critically insufficient” in terms of limiting global warming below 2 °C (CAT 2017).

In this study, we provide an assessment of LED scenarios for the Ukrainian economy. We take into account both current energy policy developments, more stringent than Ukrainian NDC contribution and consistent with the national low-carbon emission strategy initiative (USAID MERP 2017), as well as even more ambitious environmental targets. In this contribution, we mainly focus on the GHG emissions, and we consider this indicator as an integral representation of the energy consumption patterns.

2 Methodological Approach

This section describes the methodology, which we use for the assessment of Ukrainian LED scenarios. We start with an energy system TIMES-Ukraine model, which we use for the assessment of policy impacts on the energy sector and further proceed with an overview of the Ukrainian general equilibrium model (UGEM), which is used to estimate macroeconomic and sectoral effects. We also discuss the soft-linkage of TIMES-Ukraine and UGEM models, as well as some limitations of the applied methodology.

2.1 *TIMES-Ukraine Model*

TIMES-Ukraine is a typical linear optimization energy system model of MATKAL/TIMES family (Loulou et al. 2004), which provides a technology-rich framework for estimating energy dynamics in the long-run (Podolets and Diachuk 2011). The Ukrainian energy system in the model is divided into seven sectors: energy supply, electricity and heat generation, industrial users, transport, agriculture, households and services (Fig. 1).

Industrial users are further disaggregated into two categories. Energy-intensive subsectors are represented by product-specific technologies. For other industrial subsectors, we use a standard representation according to the four types of general processes: electric engines, electrochemical processes, thermal processes and other processes. Energy consumption by households and commercial sector is defined by the most energy intensive categories of consumer needs (Fig. 1).

Energy system models, like TIMES-Ukraine, are usually used for long-term analysis of energy system development paths. By changing the assumptions on useful energy demands, technologies, prices or other exogenous variables baseline

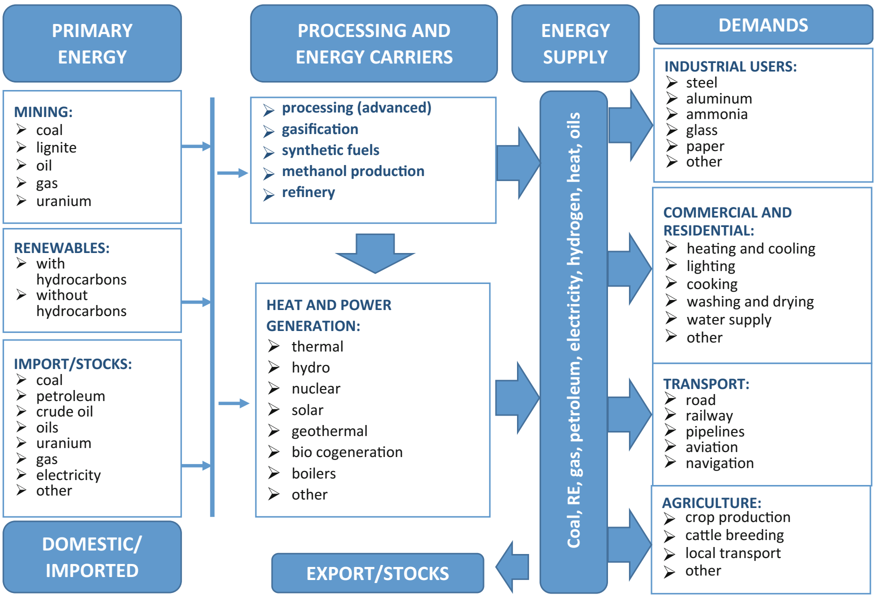

Fig. 1 Representation of the energy system in TIMES-Ukraine model

scenarios are developed. For the next step, policy scenarios are designed by imposing additional constraints or targets to the energy system. In this study, we develop one baseline scenario (BaU) and two policy scenarios. Differences between baseline and policy scenarios are further analyzed.

2.2 Dynamic UGEM Model

With energy policy impacts going beyond energy sector, we also need a modelling tool that provides a top-down view of the national economy. For this reason, in addition to the TIMES-Ukraine, we use the dynamic UGEM model. The Current version of the model is based on the static model described in Chepeliev (2014) and dynamic mechanisms introduced in TRPC (2014). It is a typical single-country recursive dynamic computable general equilibrium (CGE) model with producers divided into 40 sectors and households disaggregated into 10 groups according to their income level. Figure 2 represents key circular flows in the UGEM.

UGEM is formulated as a static model and solved sequentially over time. The Energy sector in the UGEM is represented by 7 subsectors: coal mining, extraction of the natural gas and oil, coke and oven products, petroleum products, electricity production and distribution, distribution of natural gas, heat and hot water supply. Key input data for the model is sourced from Input-Output tables, households' surveys and National accounts. It is organized in the form of Social Accounting Matrix based on the 2013 data and further updated to the 2015 using RAS method (Trinh and Phong 2013).

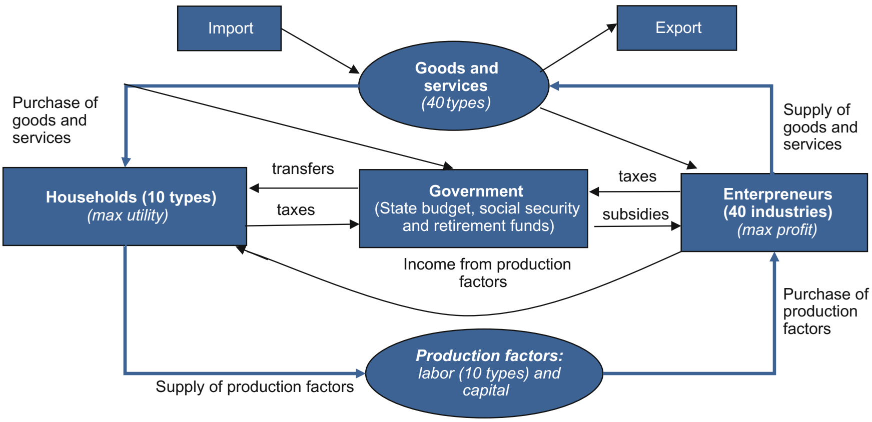

Fig. 2 Circular flows in the UGEM model

2.3 Model Linkage

To provide an assessment of LED policies in Ukraine we use a soft-linkage of TIMES-Ukraine and UGEM models (Fig. 3).

On the *first step*, we calibrate both models to match the assumptions of the BaU scenario, in particular, GDP and population projections. On the *second step*, we provide an assessment of the LED policies using TIMES-Ukraine model. As a result, we analyze policy impact on the energy sector and estimate additional investments required to reach the energy policy targets. We also estimate specific energy consumption changes relative to BaU scenario. For the *third step,* we prepare shocks for the UGEM. We map TIMES-based changes in additional investments and specific energy consumption to the UGEM classification of economic activities. *Finally*, we introduce these shocks to the UGEM and provide an assessment of economic impacts (Fig. 3).

Such an approach is not without limitations. In particular, in terms of the additional investments for the UGEM simulation, we do not assume any external sources (e.g. foreign borrowings), but use only domestically available resources. We also do not explicitly represent renewables in the UGEM and account for changes in the generation structure by altering composition of the intermediate inputs in the corresponding sectors (e.g. share of coal used for electricity generation). Finally, we make only one-way linkage from TIMES-Ukraine to UGEM, while a more consistent approach should include multiple iterations. Nevertheless, such approach can be considered more inclusive than a stand-alone application of TIMES-Ukraine or UGEM.

As many studies have shown, results of the CGE modelling can significantly depend on the values of exogenous parameters, in particular, elasticities of substitution and transformation. Sometimes, variation of these parameters can even

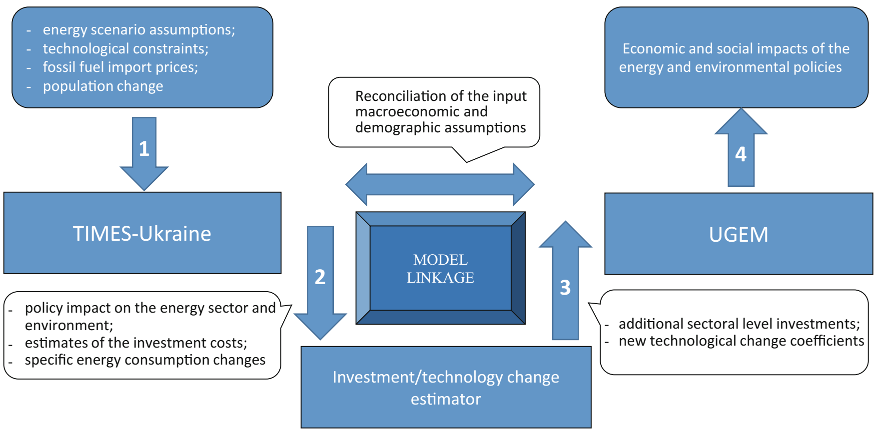

Fig. 3 TIMES-Ukraine and UGEM models linkage

change the results qualitatively, for instance, by turning net welfare gain into loss under the trade policy experiment (Taylor and von Arnim 2006). Therefore, in this study we accompany all UGEM-based estimates with error bars. We follow a Systematic Sensitivity Analysis (SSA) approach developed by Arndt and Pearson (1998) and apply a 50% variation to all 12 groups of substitution and transformation elasticities in the UGEM (Chepeliev 2014). We further derive 95% confidence intervals and indicated them using error bars. We use a triangular distribution for parameters variation and Strouds quadrature for approximation. To derive confidence intervals we assume normal distribution of the elasticities.

3 Energy Policies and Environmental Impacts

In this section, we discuss the BaU scenario and low emission development scenarios.

3.1 Business as Usual Scenario

Before moving to the discussion of long-term energy and environmental policy scenarios in Ukraine, we should consider a benchmark situation and develop a BaU path, based on the main drivers of energy demand. We assume an average 4% GDP growth rate over 2016–2050 based on the long-term forecasts of the macroeconomic model for Ukraine (Diachuk et al. 2017). For demographic forecast, we assume an −0.4% annual average population change over the same period, which corresponds to the central scenario provided by the Ukrainian Institute of Demography and Social Studies (PIDSS 2014). It is also assumed that domestic and world energy prices change in line with World Bank forecasts during 2015–2035 (WB 2017a) and 2030–2035 growth rate continues until 2050.

The BaU scenario is developed under the assumption of no fundamental changes in the energy system, i.e. current trends will continue and no new policies will be implemented. Thus resulted fuel mix and energy demand are fully defined by the demand drivers. Meanwhile gradual replacement of technologies still takes place, as the life time of existing equipment terminates.

GHG emissions under the BaU grow by almost 68% relative to 2012 levels (Fig. 4). In this study we consider only industrial processes and energy sector related GHG emissions in terms of IPCC definitions. In 2012, they amounted to 88% of total GHG emissions in Ukraine (Diachuk et al. 2017). According to the BaU scenario, Ukraine's share in global GHG emissions would almost double relative to 2015 level and reach 1.4% by 2050 under the assumption of world Reference CO_2 emissions (US EIA 2016).

Significant reductions in GHG emissions during 2012–2015 is associated with a severe economic recession and violation of Ukraine's territorial integrity. Within

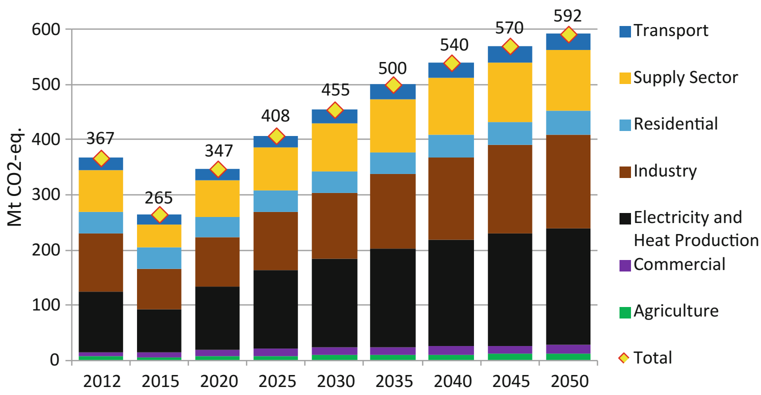

Fig. 4 Forecast of the GHG emissions in Ukraine according to the BaU scenario

the BaU scenario we assume that state sovereignty would be restored by 2020, therefore GHG emissions grow faster during this transition phase, relative to post-2020 period. Maintenance of the highly energy intensive economy like Ukraine would require significant expenses in the long-run as energy system costs may quadruple in 2050 relative to 2012 (Fig. 5). Due to the high level of depreciation, significant investments are required to replace obsolete technologies. Further depletion of fossil-fuels would even more inflate these costs and put higher pressure on the national economy.

The BaU scenario suggests that implementation of LED policies in Ukraine would primarily serve its national economic, social and environmental interests. Furthermore, any lag in moving towards this direction is only increasing cumulative energy system costs, as obsolete plants and equipment would require significant funds for their maintenance and update over time.

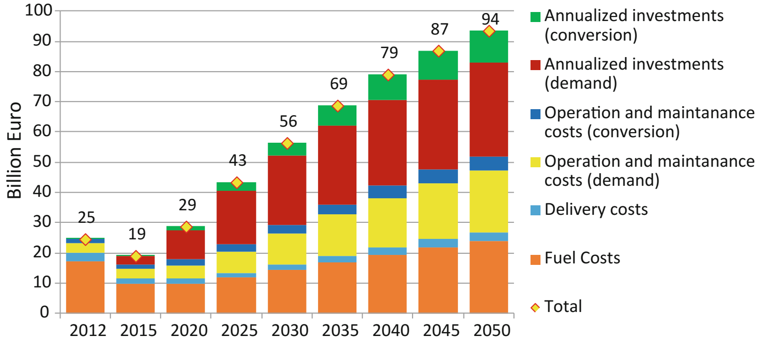

Fig. 5 Energy system costs under the BaU scenario (constant 2012 EUR)

3.2 Low-Emission Development Scenarios (LED)

LED scenarios are developed using additional assumptions imposed on the BaU path, i.e. they are based on the same macroeconomic and demographic forecasts, but differ in energy policy measures.

In accordance with Article 4, paragraph 19, of the Paris Agreement, all Parties should design long-term low GHG emission development strategies and communicate them by 2020 to the secretariat mid-century (UNFCC 2017). ***ULCDS scenario*** (Ukraine's low-carbon development strategy) is designed in the scope of Ukrainian low-carbon development Strategy initiative within the framework of USAID project (USAID MERP 2017). All energy policies are grouped into four streams: energy efficiency improvements, modernization and innovation, promotion of renewable energy (including biomass) and market transformations (such as national GHG emission trading scheme and improvements of emission taxation system). ULCDS scenario does not explicitly include national GHG emissions reduction target, but is based on the contributions of energy experts and their views on the economically feasible LED path for Ukraine.

The main goal of the second energy policy scenario is to analyze the benefits and challenges of moving towards high shares of renewables (***RE scenario***) more in line with the need to keep the global average temperature to well below 2 °C. This scenario has been developed in collaboration with the Heinrich Böll Foundation's Office in Ukraine (Diachuk et al. 2017), which supports the Greenpeace initiative in performing conceptual studies on energy system transformations with RE domination, the so called "Energy [R]evolution" (Greenpeace International 2016).

In contrast to ULCDS scenario, where the set of diverse targets and conditions are imposed, in RE scenario the largest possible share of renewables is key driving force for energy system transformation. RE scenario also assumes implementation of the Energy Community acquis (EC 2017). With such a stringent constraints, this scenario should be considered more as an exploratory assessment of RE potential and energy system flexibility, rather than guideline for specific policy measures.

Although most similar studies focus on a complete phase out of fossil fuels, in case of Ukraine, we take a 92% RE share as an economically feasible target. As our analysis shows, further increase of the RE share in GFEC results in the exponential growth of additional investments and total system costs.

In terms of GHG emissions, both LED scenarios are much more stringent than current Ukrainian NDC contribution (Fig. 6). To estimate the correspondence between LED scenarios and temperature paths a CI (2017) approach is applied. We take Ukrainian NDC level as a peak of GHG emissions in 2030 and apply required emission reduction rates for developing country afterwards. Under such an approach the ULCDS scenario corresponds to the 2.0 °C target, while RE scenario is consistent with 1.5 °C target (Fig. 6). Although the Ukrainian NDC level may seem high compared to the actual 2012 (pre-war) emissions, relative to the 1990 GHG emissions it is almost 40% lower. In addition, a significant emissions drop during 1990–2000 was achieved almost solely by sharp economic recession, therefore in case of rapid economic recovery without significant structural shifts NDC may serve as a reasonable constraint for possible emission peak.

3.3 *Energy System Effects*

Before moving to the comparison of ULCDS and RE scenarios, one particular point should be discussed in terms of results interpretation. While by 2050, RE scenario has much higher share of renewables than ULCDS, main decoupling between these two paths takes place only after 2035–2040. Therefore, in terms of cumulative changes over the whole 2012–2050 time horizon, differences between these two scenarios may not seem so large. This point can be best illustrated using GHG emissions reduction (Table 1). While in the case of the RE scenario cumulative emissions reduction is only 9% higher than in ULCDS, in the former case 2050 GHG emissions are 70% lower (85 Mt CO_2-eq. in RE vs. 285 Mt CO_2-eq. in ULCDS).

In general, both scenarios have negative total system costs, which means that additional capital expenditures are offset by associated energy efficiency improvements and reduction in fuel consumption. While the RE scenario has slightly higher total system costs than ULCDS, it is still more attractive from the economic point of view than BaU path. In other words, further maintenance of the

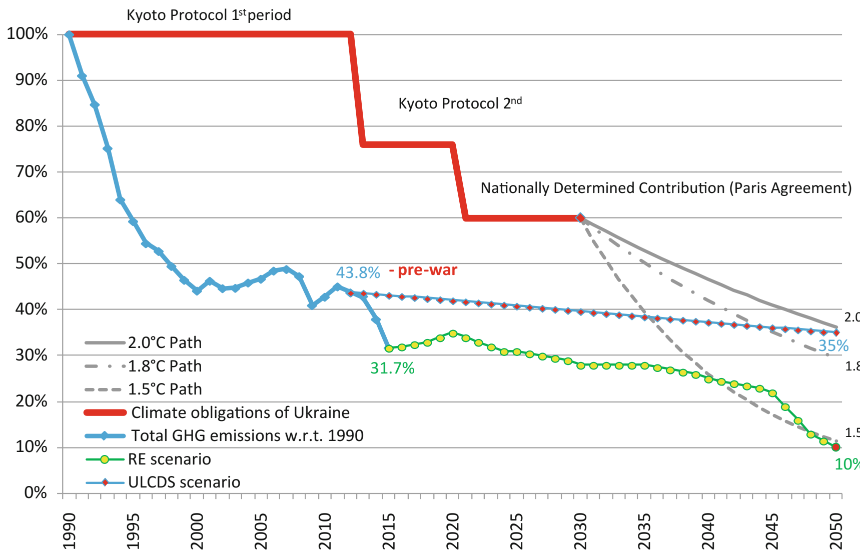

Fig. 6 LED scenarios emission and climate obligations of Ukraine. *Note* Estimates of the temperature paths for Ukraine are based on the CI (2017) methodology. Ukrainian NDC level is taken as a peak emission in 2030, afterwards annual reduction rates of 3.5% (in case of 1.8 °C path) and 8% (for 1.5 °C path) are applied to derive corresponding emission levels by 2050

Table 1 Cumulative 2012–2050 LED policy results

Indicators	Units	BaU	Change w.r.t. BaU			
			ULCDS		*RE*	
			Absolute	%	*Absolute*	%
GHG emissions	Mt CO_2-eq.	17,502	−7169	−41.0	−8718	−49.8
Total primary energy supply	Mtoe	5354.2	−1348.3	−25.2	−1820.5	−34.0
Import	Mtoe	1923.4	−815.8	−42.4	−972.0	−50.5
Final energy consumption	Mtoe	2684.7	−524.2	−19.5	−634.0	−23.6
Electricity generation	TWh	9901	−1675	−16.9	−501	−5.1
New power plant capacities	GW	101	14	13.5	133	132.2
New storage capacities	GW	0	59	–	139	–
Fuel expenditures	billion EUR (*constant 2012*)	629.4	−262.0	−41.6	−295.5	−46.9
Power plant investments	billion EUR (*constant 2012*)	120.3	−13.1	−10.9	82.9	68.9
Final demand technologies investments	billion EUR (*constant 2012*)	911.0	63.5	7.0	110.5	12.1
Total system costs	billion EUR (*constant 2012*)	734.8	−73.0	−9.9	−46.7	−6.4

Note "Mt CO_2-eq" stands for million tons of CO_2 equivalent; "Mtoe" stands for million tons of oil equivalent; "TWh" stands for Terawatt-hours; "GW" stands for Gigawatts

existing, highly inefficient energy system in the long-run, is even more expensive than transition towards 92% renewables share. As in case of BaU scenario, fuel expenditures account for almost 86% of total system costs and represent the most attractive "low hanging fruits" in terms of costs reduction.

Both scenarios positively contribute to national energy and economic security, by significantly reducing expenditures on imports, as well as final energy consumption (Table 1). While demand for electricity decreases, there is a need for new generation capacity, which is a key driver behind large additional investments in RE scenario. At the same time, ULCDS requires even lower power plant investments than BaU. However, both scenarios need additional investments to boost changes in final demand technologies, including expenditures on domestic appliances, vehicles, industrial machines, as well as insulation. In both cases, this category accounts for the largest share of additional investments.

Both LED scenarios assume significant change in generation mix (Fig. 7). Even under ULCDS path, nuclear energy would lose its dominating share after 2035. Existing nuclear plants would be gradually decommissioned, while new nuclear units (under current forecasts) would not be able to compete with other generation technologies. As a result, new coal power plants become a basis of the load curve, while 2/3 of the demand is covered by renewables. As RE scenario shows (Fig. 7), apart from hydro energy, other renewables (solar, wind, biomass) have even higher technically feasible potential. Implementation of their potential would require additional measures and technical solutions. In particular, they should include development of the grid and long-term electricity storage technologies, implementation of the demand control system for the load curve smoothing, further development of the transmission capacities and elimination of operational constraints that renewable generation faces for the integration to the national energy system. Additional measures should include introduction of tariff incentives for the renewable energy co-generation and development of the attractive funding opportunities. The latter one is especially important for Ukraine, as under the current conditions, high level of the green tariffs is almost fully offset by unaffordable funding options.

Changes in total final consumption include a decrease in energy use due to the implementation of energy efficiency (EE) measures, penetration of renewables on the energy market and significant increases in electricity consumption (Fig. 8). Due to the transition to market prices for natural gas in Ukraine, which started in 2009 for industrial users and in 2015–2016 for households, natural gas consumption gradually reduces and is substituted by other sources within ULCDS scenario. One of the methodological reasons behind this is that LED scenarios do not include

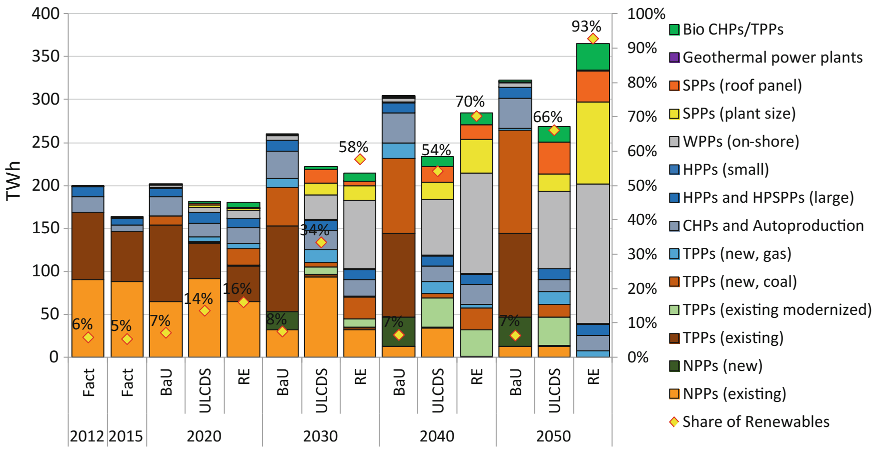

Fig. 7 Electricity generation in LED scenarios for Ukraine. *Note* CHPs—combined heat and power plants; TPPs—thermal power plants; SPPs—solar power plants; WPPs—wind power plants; HPPs—hydro power plants; HPSPPs—hydro pumped storage power plants; NPPs—nuclear power plants

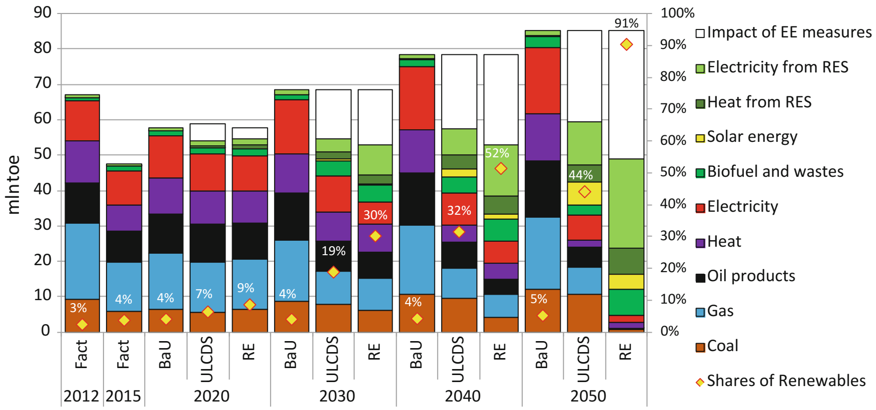

Fig. 8 Total final consumption in LED scenarios in Ukraine

stringent ecological constraints (in case of RE scenario share of renewables is the only target), as a result there is no impact on the price of carbon-intensive fuels and technologies. At the same time, the renewables share doubles by 2050 and the corresponding emissions reduction es not put significant financial pressure on the final consumers. In particular, each additional percentage point of the renewable energy share requires 1 bn Euro investments on aggregate over 2015–2050.

4 Economic Assessment of LED Scenarios

In this section, we use the dynamic UGEM model to provide an assessment of economic effects of LED scenarios. We start with the discussion of macroeconomic effects and further proceed with the sectoral impacts. All results are estimated relative to the BaU scenario discussed in Sect. 3 and show additional changes associated with the implementation of LED scenarios.

4.1 *Macroeconomic Effects*

According to our results, both LED scenarios are associated with positive macroeconomic effects. While in the short run, additional GDP growth (w.r.t to BAU scenario) is relatively low (1–2%), in the mid- and long-term it can reach up to 12–16% (Fig. 9). Key insights from this result is that over time energy efficiency improvements overstate associated investment costs. This is one of the

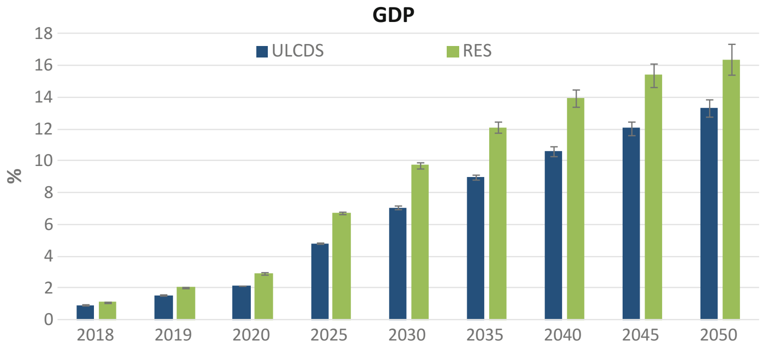

Fig. 9 Macroeconomic effects of LED policies implementation (w.r.t. BaU, %). *Note* Error bars indicate 95% confidence intervals for substitution and transformation elasticity changes under the SSA approach. See Sect. 2.3 for more details

"low hanging fruits" of the Ukrainian energy sector, as an introduction of new technologies can substantially reduce both energy and carbon intensity, as well as benefit economic development.

Overall, the RE scenario results in a higher GDP and output growth rates than ULCDS path, mainly due to the much higher additional investments and corresponding energy efficiency improvements. Although ULCDS scenario exploits most of the "low hanging fruits", there is still some space for environmentally friendly economic development. At the same time, a continuously growing necessity to accumulate additional investments can be seen as a main challenge towards implementation of the RE scenario. In this context, a sectoral contribution of the additional investments differs significantly by scenarios. In case of ULCDS policies, key contributions are provided by households, which account for over 60% of additional investments. At the same time, under the RE scenario, residential users' contribution does not change in value terms, but much higher investments are required from the industrial users, in particular, electricity producers (Fig. 10).

According to the National accounts (SSSU 2016), Ukrainian households' expenditure on capital goods are around 11% of the total national investments (1,3 bn EUR in 2015), while only implementation of the ULCDS scenario additionally requires 31 bn EUR over the 2017–2050 period. This may seem to require a substantial change in the households' consumption patterns and a significant increase of the marginal propensity to accumulate. At the same time, estimates of the additional residential investments, provided in this chapter, include not only capital goods, but also some final consumption expenditures (electrical appliances, motor vehicles etc.). In this context, additional residential investments (in case of both LED scenarios) represent a relatively small share of the total final consumption expenditures—less than 0.5% over the 2017–2050 period.

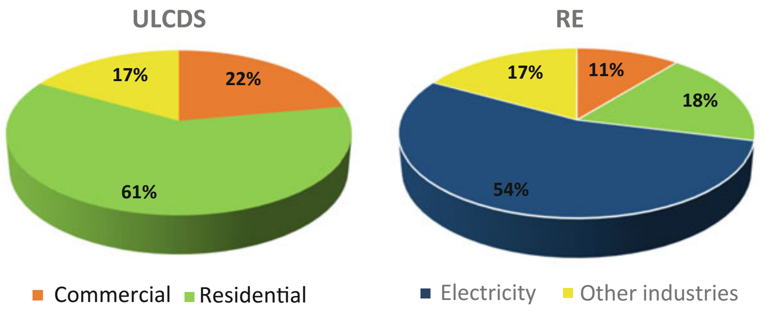

Fig. 10 Distribution of the additional investments by sources in LED scenarios, 2017–2050 (w.r.t. BaU, %)

With growing GDP, households also experience positive impacts of LED policies. In the short run, they are relatively insignificant, and even slightly negative for the RE scenario, but in the mid and long term, additional income growth can reach up to 12–14% (Fig. 11). During initial years, RE scenario has lower real income growth rates as much higher additional investments are needed for its implementation (compared to ULCDS), while efficiency improvements are distributed over time and have larger impact in the mid-term (by 2020–2025).

Households of the lower income deciles experience higher income growth rates than the richer households. Higher decile households have bigger share of services in their final consumption, and as domestic prices for services grow quicker than aggregate consumer price index, lower income deciles benefit more.

Both GDP and households' income estimates seem to be robust under elasticity changes, as deviations within 95% confidence intervals in most cases do not exceed 5% of the estimated values (Figs. 10 and 11).

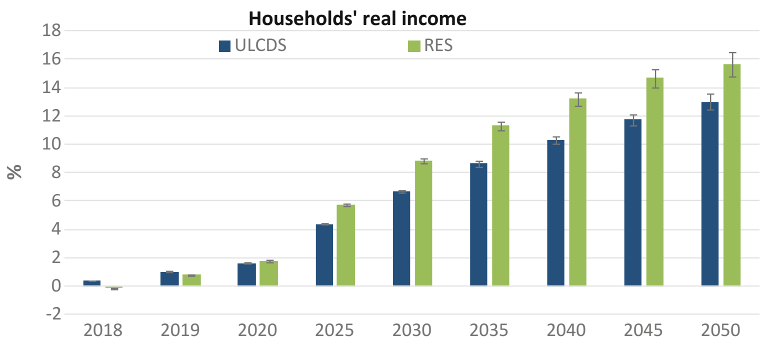

Fig. 11 Impacts of LED policies implementation on households real income (% w.r.t. BaU). *Note* Error bars indicate 95% confidence intervals for substitution and transformation elasticity changes under the SSA approach. See Sect. 2.3 for more details

4.2 Sectoral Effects

Implementation of LED scenarios is accompanied with significant structural changes, driven by the impacts of energy efficiency and fossil fuel substitution on productivity growth and price effects.

In general, both LED scenarios lead to reductions in fossil fuels mining and processing industries (Fig. 12). This is especially representative in the case of RE scenario, as coal mining, gas distribution and coke production decline by over 40% relative to BaU in 2050. Energy efficiency improvements and fossil-fuel prices reduction contribute to the output growth in some energy intensive industries, including basic metals, electricity and heating. As the share of biomass increases, agriculture and wood processing sectors raise their output to meet the growing demand. Some resources from mining and fossil fuel production shift towards services, as a result their output share slightly increases.

On average, estimates of the output changes show a higher degree of uncertainty compared to aggregate macroeconomic effects. For some sectors, they even indicate the possibility of sign change, like in case of electricity industry under ULCDS scenario (Fig. 12). Nevertheless, in most cases results do not change qualitatively, while high uncertainty around quantitative estimates is justifiable considering the role of substitution elasticities.

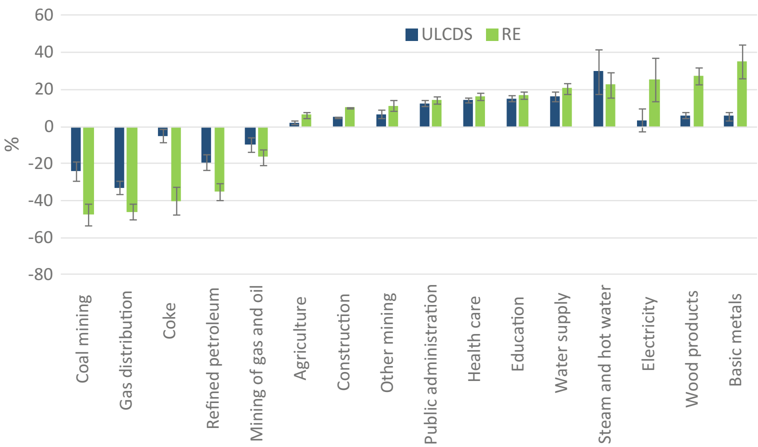

Fig. 12 Changes in the sectoral output under LED scenarios in 2050 (w.r.t. BaU, %). *Note* Error bars indicate 95% confidence intervals for substitution and transformation elasticity changes under the SSA approach. See Sect. 2.3 for more details

5 Policy Recommendations

Implementation of both LED scenarios is associated with significant challenges for Ukraine, especially in terms of current energy market structure, institutional capacity, social, economic and political conditions. In this context, policies and measures required for the implementation of ULCEDS scenario (consistent with 2 °C target) are essential since they serve as a basis for further movement towards RE paths (consistent with 1.5 °C target). Indeed, the ULCEDS scenario itself would require the whole set up of new policy mechanisms, significant market and institutional transformations etc., and the transition from the ULCEDS to the RE path would include scaling the intensity of policy measures (e.g. emission taxation level). In addition, most RE path-oriented measures are implemented after 2035–2040, which enables the possibility of a smooth transition from ULCEDS to RE during this period.

While implementation of both scenarios provides double dividends and is socially acceptable in the long run, existing institutional environment and inefficient market framework can pose significant challenges. In particular, this includes a necessary transition to the new institutional model of the Ukrainian energy market. The basics of such market set up (innovative development, networks' integration, consumers' empowering etc.) are already identified in the Ukrainian Energy Strategy (CMU 2017). At the same time, target indicators of the Energy Strategy are inconsistent with goals of some other strategic energy documents, such as Ukrainian low-carbon development strategy initiative. This identifies one of the key challenges of the institutional transformation in the Ukraine, which includes consistency and coherence of the energy strategic planning.

Elimination of the market disparities should readily contribute to the solution of another challenge, in particular, energy efficiency improvements, which may significantly reduce fuel costs. While all final consumption sectors have high energy efficiency potential, key contribution is associated with industry and households. Therefore, main policy efforts and government support should be focused on these two sectors. Transformation of the energy system under RE scenario would require significant additional investments—over two times higher than under ULCEDS. Even further reduction of fuel costs would not compensate increasing total system costs within RE scenario.

In terms of more specific challenges and policy measures, there are several high-priority steps that should be implemented. While Ukraine has successfully implemented a tariff reform in the energy sector (OECD 2016) and moved from uniform to targeted subsidies, over half of the households still do not have incentives and resources for energy efficiency improvements, since they benefit from the subsidized price rather than receiving any direct monetary transfer which could stimulate energy savings. Even with a more efficient subsidization system, due to the low level of households income, it would take a long time to substantially reduce volumes of subsidization. Over that period, National budget may experience significant pressure, as in 2016 subsidy-related transfers reached over 1.6 billion EUR or 7% of the National budget expenditures (STSU 2017).

Another potential challenge includes incentives for industrial users. As of the end of 2017, CO_2 emitters are facing an emission tax of 0.01 EUR per ton of CO_2, which is too small for achieving environmental targets.

In a broader context, national energy markets transformation towards transparency and competitiveness becomes a necessary condition of LED policies success. Remaining highly ineffective, Ukrainian energy markets are not able to sufficiently perform their key functions and fully integrate into the global environment. As a result, excessive government interventions continuously take place, which leads to the price distortions, as well as creates high risks for potential investors. Ukraine's access to the European legal framework through joining the Energy Community has defined a more specific direction and set up a way forward for efficient sectoral reforms. This form of integration should be further reasonably exploit to establish effective energy market design and technological renovation of the Ukrainian energy system.

6 Conclusion

With one of the highest levels of energy and emission intensities in the world, Ukraine has a high potential to exploit the "low hanging fruits" of the energy sector transformation by implementing LED policies, which can benefit both economy and environment.

According to our results, further maintenance of the existing highly inefficient energy system in the long-run is even more expensive than transition towards 92% renewables share. Key differences between ULCEDS and RE scenarios, both in terms of policy measures and results, arise after 2035–2040, which enables the possibility of smooth transition from ULCEDS to RE during this period. Only the RE scenario provides sufficient national contribution in terms of limiting global warming well below 2 °C.

With initially low level of energy efficiency in Ukraine, both LED policies result in positive macroeconomic and sectoral effects, both in terms of GDP and households real income growth, with better perspectives in case of the RE scenario, which at the same time requires 3 times higher investments. In this context, Ukraine benefits from double dividends under both policy options, while RE scenario also provides an economically acceptable way of going from relative to absolute decoupling.

Finally, adjustments in the institutional environment and market framework are identified. First, the energy strategic planning set up must be improved to avoid inconsistencies between strategic energy documents (e.g. Energy Strategy, Low-carbon Development Strategy etc.), including a social and political consensus around key strategic targets. Second, an efficient pricing of fossil fuels is required, in particular price signals for industrial users, as well as more transparent and market-oriented approach to residential consumers, with more targeted subsidies and elimination of cross subsidization in the electricity sector. Finally, Ukraine should move to competitive energy markets (in particular, fully implement Third Energy Package), as well as proceed with further integration to the ENTSO-E.

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