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Heat pumps are widely used in buildings due to high energy performance and environmental-friendliness. 2010/31/EU Directive of the European Parliament and Council requires assessing the consumption of primary energy generated from renewable sources when calculating the energy performance of buildings. However, the equation given in the 2009/28/EU Directive and guidelines 2013/114/EU of the European Commission does not take into account the amount of energy supplied by electric heat pumps into buildings. The paper presents the method that does not assess the energy input of primary sources for transforming electric power and for this reason, the calculations result in a lesser amount of energy than the ones obtained by the method of 2013/114/EU Directive. The calculation results proved that using merely heat pumps in nearly zero-energy buildings will not ensure the necessary amount of energy from renewable primary energy sources. Hence, to ensure the lacking amount of energy other renewable energy sources, such as solar panels, wind power plants, hydro power plants, biofuel, etc. are necessary to use.

KEYWORDS: heat pumps, primary energy, renewable energy, non-renewable energy, energy performance of buildings.

Introduction

A heat pump is equipment that transforms aerothermal, geothermal or hydrothermal energy into higher-temperature heat that is used to heat buildings and/or water.

High efficiency of heat pumps and the requirements of energy performance of buildings becoming more demanding are the reasons why researchers' interest in heat pumps as one of the most promising heating sources increases accordingly. However, the method of calculating the amount of heat supplied to the building by heat pumps fed on renewable and non-renewable sources is not widely discussed in literature sources. For example, Mendes compares absorption heat pumps fed on solar energy to pressure heat pumps in respect of primary energy use (Mendes *et al.* 1998). Gea analyses an up-to-date air heat pump system combining dryer wheel technology and radial cooling/heating. They assess the need for primary energy in the processes of cooling

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and drying, as well as cooling, drying and heating by comparing the potential of such hybrid systems in saving primary energy with a traditional air heat pump system (Gea *et al.* 2011). Balta assess the exergetic energy released in the building from a primary energy source, which is the method applied in the premises heated by a geothermal heat pump (Balta *et al.* 2008). Moreover, Huchtemann compares highly efficient condensing boilers to heat pumps, assess the efficiency of various types of fuel used, and the factors of primary energy and CO_2 emission conversion (Huchtemann *et al.* 2012).

Similarly, by comparing two systems for heating water, namely a heat pump combined with water heating solar panels, and a gas boiler, Tagliafico estimates the possibility to save primary energy. The research has been performed on pools, but most of the criteria and results of the analysis are valid for buildings in need of hot water as well (Tagliafico *et al.* 2012). Further, Tagliafico also examines a heat pump combined with solar panels and used for heating a variety of water types (Tagliafico *et al.* 2014). Zhaon analyses heating and cooling systems including a heat pump with a gas-driven engine, and propose using residual heat from the engine to reach higher primary energy coefficients (Zhaon *et al.* 2011). Lee compares two types of heat pumps (fed on electricity and gas) (Lee *et al.* 2012). Teng assess the influence of gas turbine capacity of an absorption heat pump and the strategy of its use on the consumption of primary energy in a building (Teng *et al.* 2014).

A new method of assessment is presented by Zhang who analyses the seasonal primary energy indicator of a gas-driven heat pump of a water heater (Zhang *et al.* 2014). Elgendy analyses the characteristics of a gas-driven heat pump with an integrated heat recovery/regeneration subsystem, focusing on the temperature of outflowing water, heating capacity and primary energy coefficients (Elgendy *et al.* 2014).

In regard to the primary energy efficiency criterion, Wu compare an electric soil heat pump with absorption soil heat pump, and estimate the influence of thermal imbalance of soil on energy efficiency indicators. In their further research (Wu *et al.* 2013), Wu analyses a combined heating/cooling/hot water preparation system with a geothermal absorption heat pump used in cold climate zones. During the simulation, the imbalance of soil has been diminished and a part of recovered condensation/absorption heat used to produce hot water by a heat pump. Thus, such a combined system improves the efficiency of primary energy consumption (Wu *et al.* 2014).

The possibility of using heat compensation equipment with a thermo siphon in case of heating buildings by soil heat pumps in cold climate zones is discussed by You who claims that long-term exploitation of a heat pump reduces its efficiency due to soil cooling down (You *et. al.* 2014). Havelsky uses primary energy indicators to analyse cogeneration system connected to heat pumps (Havelsky 1999). Hebenstreit looks at the operating input, primary energy consumption efficiency, and greenhouse gas emission to study the possibility of using a heat pump in an active condensation system by regenerating heat from biomass-driven boilers (Hebenstreit *et. al.* 2014). Yang considers potential and efficiency of a heat pump in ventilating and heating a greenhouse by the use of redundant thermal air energy formed therein (Yang *et al.* 2013). A hybrid heating system composed of a sewage thermal energy-driven heat pump and a gas boiler is analyzed by Li who examine its optimal operation strategy in order to reduce annual energy need (Li *et al.* 2013).

Bayera assess the pumps in respect of the reduction of CO_2 emission (Bayera *et al.* 2012). They presuppose that electric power generation, becoming more ecological in the future, will lead to the increased efficiency of the pumps. Having compared various types of heat pumps and their operational principles, Sarbu states that better heat pump efficiency indicators are reached by combining heating and cooling as well as increasing the amount of renewable energy in the total of electric power used (Sarbu *et al.* 2014). The comparison of a heat pump to a gas boiler is presented by Cabrol taking into account CO_2 emission (Cabrol *et al.* 2012). They claim that increasing the mass of the building or installing additional heat insulation enables reaching an acceptable thermal comfort level during the heating season even if the air heat pump is not operating at maximum capacity. Rosiek estimates the amounts of primary energy consumption and CO_2 emission by comparing different building cooling; heating and electric power generation systems based on the combination of renewable energy sources with traditional systems (Rosiek *et al.* 2013).

The presented work analyzed existing and developing systems and methodologies of consumed and generated energy by heat pumps. The objectives are to propose the methodology evaluating renewable energy generated by electric heat pump while considering factors such as the primary renewable and non-renewable energy, efficiency of heat pumps, the proportion of primary renewable energy in a building's overall energy consumption.

Research problem definition

The efficiency of traditional heat sources (gas, solid fuel, electric boilers, etc.) is defined by the useful efficiency coefficient $\eta_{H.eq}$, the value of which shows the ratio of the amount of thermal energy produced by a heat source to the amount of thermal energy present in the energy source (gas, solid fuel, electricity, etc.) used to produce heat. Thus, the dimension of the coefficient stands as "the amount of thermal energy/ "the amount of thermal energy".

The efficiency of an electric heat pump is assessed by a seasonal performance factor η_{SPF} that defines the ratio of the amount of thermal energy produced by a heat pump to the amount of electricity used by the pump to produce that energy. η_{SPF} dimension can be expressed as "the amount of thermal energy"/ "the amount of electricity". The η_{SPF} value of a heat pump is estimated by testing in accordance with the LST EN 15450:2008 (2008) Standard. If the value of useful efficiency of electricity generation η_{el} is known (i.e. the ratio between the generated amount of electric power and the amount of energy in the energy sources used to produce that energy), the value of electric heat pump coefficient $\eta_{H.eq}$ can be estimated as follows:

$$\eta_{H.eq} = \eta_{SPF} \cdot \eta_{el} \tag{1}$$

If $(1 - \eta_{H.eq})>0$, the value of $(1 - \eta_{H'eq})$ indicates the amount of thermal energy present in the energy source (gas, solid fuel, etc.) that was not converted into thermal energy by that source.

$(1 - \eta_{H'eq})<0$ suggests that more thermal energy was produced while transforming the energy of a source into thermal energy than the amount of energy initially held by the energy source. In such a case, a part of energy is generated from renewable energy rather than the thermal energy initially present in the source. As follows, the value of $(\eta_{H.eq-1})$ defines the part of thermal energy that may be ascribed to the thermal energy generated from renewable sources and initially present in the traditional source (gas, solid fuel, etc.).

The guidelines of the European Commission 2013/114/EU, specifying the requirement of the EU Directive 2009/28/EU to calculate the part of renewable energy generated using different technology-based heat pumps, provides a statistical method with the following equation:

$$E_{ERES} = E_{usable} \cdot \left(1 - \frac{1}{\eta_{SPF}}\right) \tag{2}$$

here: E_{usable}, the amount of energy suitable for use and supplied by heat pumps is estimated by equation (3):

$$E_{usable} = H_{HP} \cdot P_{rated} \tag{3}$$

here: H_{HP} – the equivalent amount of hours of a heat pump operating at full load (h);

P_{rated} – capacity of a heat pump of the respective type (kWh).

To perform statistical calculations the H_{HP} values have to be estimated in accordance with the data given in the guidelines 2013/114/EU of the European Commission that are linked to the climate conditions of the respective EU member state. Thus, depending on the climate conditions and the type of a heat pump, fixed H_{HP} values unrelated to the energy needs of a building were determined in the corresponding climate zones. The 2010/31/EU Directive requires estimating the energy performance of buildings in regard to the primary energy input, whereas equation (2), given in 2013/114/EU, enables estimating “the part of renewable energy generated by heat pumps” that is related neither to the requirements of the 2010/31/EU Directive nor the LST EN 15450:2008 Standard.

Equation (3) cannot be applied for calculating primary energy since the physical meaning of its multiplier $(1-\frac{1}{\eta_{SPF}})$ is as follows:

$$1-\frac{1}{\eta_{SPF}}=1-\frac{1}{\dfrac{thermal\ energy\ amount}{electric\ power\ amount}}=\frac{thermal\ energy\ amount-electric\ power\ amount}{thermal\ energy\ amount} \quad (4)$$

In equation (4), thermal and electric power cannot be taken as the same, because the latter is generated from the energy of a primary energy source (gas, oil, solid fuel, etc.). Yet, electricity in not a primary energy source that is used in heat pumps to produce thermal energy. To generate electric power the EU member states use less than a half of energy available in primary energy sources. According to the data provided in the guidelines 2013/114/EU of the European Commission, the average value of useful efficiency of electricity generation η_{el} makes up 0.455 in the EU member states. Consequently, if thermal and electric power were handled identically, then the impact of energy from renewable sources used in heat pumps on the calculation of the amount of energy generated from renewable sources would be reduced by 2.2 times (1/0.455=2.2) in equation (4). In that case, the calculation using equation (1) would result in an increased amount of thermal energy produced from renewable sources than it should actually be.

Solution to the problem

To calculate the amount of renewable and non-renewable energy supplied to a building by electric heat pumps, the following energy balance condition was composed:

“the total amount of thermal energy supplied to the building systems” = “the amount of thermal energy generated using electric power and supplied to the building systems” + “the amount of thermal energy generated using renewable energy sources and supplied to the building systems”.

The condition may be put into an equation as follows:

$$E_{usable}=\frac{E_{usable}}{\eta_{H.eq}}+E_{ERES} \quad (5)$$

Hence, the amount of thermal energy from renewable energy sources used in a building may be estimated in such a manner:

$$E_{ERES}=E_{usable}-\frac{E_{usable}}{\eta_{H.eq}}=E_{usable}\cdot(1-\frac{1}{\eta_{H.eq}}) \quad (6)$$

Similarly, the energy supplied to a building from electric heat pumps is expressed as in equation (7):

$$E_{ERES}=E_{usable}\cdot(1-\frac{1}{\eta_{SPF}\cdot\eta_{el}}) \quad (7)$$

Table 1 presents the comparison of the calculations performed using equations (2) and (7). The analysis discusses the calculation results of thermal energy produced using renewable sources in electric heat pumps per one kWh of thermal energy supplied by the pumps to the building systems.

The amount of thermal energy from renewable sources used in buildings obtained following equation (1) is from 1.43 to 4.96 times higher **(Table 1, column 5)** than that obtained by equation (7). This is because equation (1) does not take into account the thermal energy of energy sources used to generate electricity.

Table 1

Comparison of thermal energy calculations according to formulas/ equations (2) and (7)

No.	Heat pump n_{SPF}, unit.	Amount of energy from renewable sources by equation (7), kWh	Amount of energy from renewable sources by equation (2), kWh	Calculation difference in the amount of renewable energy, times [column 4/ (column 3]	Amount of energy from non-renewable sources by equation (7), kWh	Amount of energy from non-renewable sources by equation (2), kWh	Ratio "renewable/ non-renewable" energy calculated by equation (7)	Ratio "renewable/ non-renewable" energy calculated by equation (2)
1	2	3	4	5	6	7	8	9
1.	2.5	0.121	0.600	4.964	0.879	0.400	0.138	1.500
2.	3.2	0.313	0.688	2.195	0.687	0.313	0.456	2.200
3.	3.5	0.372	0.714	1.920	0.628	0.286	0.593	2.500
4.	4.5	0.512	0.778	1.520	0.488	0.222	1.048	3.500
5.	5	0.560	0.800	1.427	0.440	0.200	1.275	4.000

If the thermal energy used by energy sources to generate electric power is not estimated, the value of the ratio between "renewable/non-renewable thermal energy" achieved using low-efficiency heat pumps (η_{SPF} =2.5) is 1.5, and when η_{SPF} =5, the value makes up as much as 4.0 **(Table 1, column 9)**. Analogous calculation by equation (7) demonstrates that the value of the ratio "renewable/non-renewable thermal energy" makes up as little as from 0.138 to 1.275 **(Table 1, column 8)**.

The calculation of renewable/non-renewable primary energy of electric heat pumps is related to the values of primary energy factors from electric power. The estimation of these values takes into account the amount of renewable/non-renewable primary energy used by all energy sources to generate electricity, renewable/non-renewable primary energy input for energy transportation, and primary energy losses in electricity networks. In this case, the values of primary energy factors cover not only energy sources, but also the value of useful efficiency of electricity generation η_{el} and the losses in electricity transportation. The Lithuanian normative documents in construction assume that for the calculation of electric power input in buildings electric power supplied from electricity networks is f_{PRr} =0 and f_{PRn} =2.8.

The amount of non-renewable primary energy supplied to the building systems by heat pumps used therein to generate thermal energy from electric power may be estimated as follows:

$$\frac{E_{usable}}{\eta_{SPF}} = E_{Electricity\_total} \quad (8)$$

$$E_{Electricity\_total} - E_{Electricity\_from\_ren\_source(HYDRO,PV,WIND)} = E_{usable} \quad (9)$$

here: $E_{Electricity\_total}$ – total amount of electricity, consumed by heat pumps.

$E_{Electricity\ from\ ren\ source\ (HYDRO,\ PV,\ WIND)}$ – amount of electricity from renewable sources (hydro, PV, wind).

The amount of renewable primary energy, supplied by electric heat pumps to the building systems, includes the renewable primary energy of electric power consumed in the pumps and the energy of renewable sources, calculated by equation (7). This amount may be estimated as follows:

$$E_{PRn} = \frac{E_{usable}}{\eta_{SPF}} \cdot f_{el.PRn} \quad (10)$$

$$E_{PRr} = \frac{E_{usable}}{\eta_{SPF}} \cdot f_{el.PRr} + E_{usable} \cdot \left(1 - \frac{1}{\eta_{SPF} \cdot \eta_{el}}\right) \cdot f_{HP.PRr} + E_{Electricity\_from\_ren\_source(HYDRO,PV,WIND)} \quad (11)$$

here: $f_{el.PRn}$ – non-renewable primary energy factors from electric power (unit), which is accepted here as $f_{el.PRn}$ =2.8 in calculating;

$f_{el.PRr}$ – renewable primary energy factors from electric power (unit). In the present calculations it is accepted that $f_{el.PRr}$ =0, but renewable energy sources may also be used for generating electricity and for this reason, $f_{el.PRr}$ may be >0. For example, if electricity from hydro power plants is used, then $f_{el.PRr}$ =1, $f_{el.PRn}$ =0.5. Electricity from PV power plant is used, then $f_{el.PRr}$ =1, $f_{el.PRn}$ =0.7; electricity from wind power plant is used, then $f_{el.PRr}$ =1, $f_{el.PRn}$ =0.3;

$f_{HP.PRr}$ – renewable primary energy factors from heat pumps (unit). According to the order determined by the LST EN 15450:2008 Standard, renewable primary energy $f_{HP.PRr}$ =1.

Table 2 provides the calculation results of primary energy per one kWh to the amount of thermal energy supplied by heat pumps to the building systems; i.e. when E_{usable}=1 kWh, according to equations (10) and (11).

The calculations show that when $f_{el.PRn}$ =2.8, $f_{el.PRr}$ =0 and η_{el}=0.455, the ratio of renewable and non-renewable energy supplied by electric heat pumps to a building E_{PRr}/E_{PRn}=1 can only be achieved when heat pumps η_{SPF} ≥5 **(Table 2, line 5).**

The calculation of renewable and non-renewable energy ratio by equation (2) given in the 2009/28/EU Directive and the guidelines 2013/114/EU of the European Commission **(Table 1, column 9)** is different from the calculation results of renewable/non-renewable energy ratio presented herein **(Table 2, column 5)** by 4 to 14 times.

Table 2

Primary energy supplied from electric heat pumps calculated according to equations (10) and (11)

No.	Heat pump η_{SPF}, unit	Amount of non-renewable primary energy by equations (8), E_{PRn}, kWh	Amount of renewable primary energy by equations (9), E_{PRr}, kWh	Ratio E_{PRr}/E_{PRn}
1	2	3	4	5
1.	2.5	1.120	0.121	0.108
2.	3.2	0.875	0.313	0.358
3.	3.5	0.800	0.372	0.465
4.	4.5	0.622	0.512	0.822
5.	5	0.560	0.560	1.001

Table 3 gives the 2011 data on the f_{PRn} values of electric power used for calculation in the building standards of some EU members.

The pumps that are most often used to heat buildings and water are soil-water heat pumps with η_{SPF} target value of 4.0 for new buildings in Central Europe. Table 4 gives the calculation results of E_{PRr}/E_{PRn} (per 1 kWh of thermal energy supplied by heat pumps to the building systems, by formulas/equations (8) and (9)) in electric heat pumps with η_{SPF}= 4 in the EU members given in Table 3 and Lithuania, as well as the η_{SPF} values of electric heat pumps that enable achieving E_{PRr}/E_{PRn}=1 in the mentioned countries. To perform the calculation the average value of useful efficiency of electricity generation η_{el} that makes up 0.455, and $f_{el.PRr}$=0 was applied.

As the data in Table 4 shows, in all the countries discussed except Sweden, the ratio of thermal energy supplied by electric heat pumps to a building E_{PRr}/E_{PRn}=1 can be achieved by very high-efficiency pumps with η_{SPF} value varying between 4.8 and 5.2, while in Sweden the same ratio can be reached with pumps having η_{SPF} =4.2. Analogous results were obtained having performed calculations on electric heat pumps applied for cooling buildings. In this case, the value η_{SPF} was replaced

Table 3

f_{PRn} values of electric power in the building standards of the EU members

Country	f_{PRn}
France	2.58
Germany	2.60
Holland	2.56
Poland	3.00
Spain	2.60
Sweden	2.00
The United Kingdom	2.92

Table 4

Comparison of E_{PRr} and E_{PRn} per 1 kWh of thermal energy supplied by electric heat pumps to a building in different EU members

No.	EU member	Heat pump η_{SPF}, unit	Amount of non-renewable primary energy by equation (8), E_{PRn}, kWh	Amount of renewable primary energy by equation (9), E_{PRr}, kWh	Ratio E_{PRr}/E_{PRn}
1	2	3	4	5	6
1	France	4.0	0.645	0.451	0.699
2		4.8	0.538	0.542	1.009
3	Germany	4.0	0.650	0.451	0.693
4		4.8	0.542	0.542	1.001
5	Holland	4.0	0.640	0.451	0.704
6		4.8	0.533	0.542	1.016
7	Poland	4.0	0.750	0.451	0.601
8		5.2	0.577	0.577	1.001
9	Spain	4.0	0.650	0.451	0.693
10		4.8	0.542	0.542	1.001
11	Sweden	4.0	0.500	0.451	0.901
12		4.2	0.476	0.477	1.001
13	The United Kingdom	4.0	0.730	0.451	0.617
14		5.2	0.562	0.577	1.028
15	Lithuania	4.0	0.700	0.451	0.644
16		5.0	0.560	0.560	1.001

with η_{EER} in the calculations in Table 2. To cool a building air-air electric heat pumps with η_{EER} target value of 2.8 are usually used, whereas soil pumps with η_{EER} target value of 3.8, and water pumps with η_{EER} target value of 4.3 are rarely used for the same purpose. In this case, the ratio E_{PRr}/E_{PRn}=1 can be achieved by using the pumps of considerably higher η_{EER} values.

Such a striking distinction in the calculation results obtained by equations (2) and (7) poses a question on the difference between the assessments of renewable energy generated by a heat pump for heating a building according to 2013/114/EU Directive and the method proposed in this paper.

For the present analysis, a low thermal capacity single-flat building with 100 m^2 of heated area satisfying the requirements of B energy performance label (according to STR 2.01.09:2012) was selected; the building has the following parameters:

- energy input for heating: $383 \cdot A_p^{-0,22} = 383 \cdot 100^{-0,22}$ = 139 kWh/m^2 annually;
- soil-water heat pump with η_{SPF} =3.5;
- average temperature of premises during heating season: 20 ^{o}C;
- average outdoor temperature during heating season: 0.6 ^{o}C‘
- duration of heating season: 220 days.

To heat a low thermal capacity building in the Lithuanian climate conditions the heat pump power P_{rated} (kWh) is determined at -27 ^{o}C temperature with a reserve coefficient of 1.1; thus, the approximate calculation can be done in the following manner: 1.1*(139 kWh/m^2 annually)*(100 m^2)/(220 days)*(24 h)*(20 ^{o}C+27 ^{o}C)/(20 ^{o}C-0,6 ^{o}C)=7 kW.

To generate (139 kWh/m^2)*(100 m^2)=13900 kWh of energy annually a 7 kW capacity heat source should be in operation at full capacity and optimal performance for (13900 kWh)/(7 kW)=1986 h. However, the heat pump does not operate at full capacity during the whole operational period, which is why the actual operational period becomes longer. In *Table 1*, the 2013/114/EU method provides for 1.25 times higher heat pump operational cost for cold climate zones making up 2470 h in total. Therefore, according to this method, the amount of renewable energy generated by the heat pump annually is as follows:

$$E_{usable} = H_{HP} \cdot P_{rated} = 7 \cdot 2470 = 17290 \quad (12)$$

$$E_{ERES} = E_{usable} \cdot (1 - \frac{1}{\eta_{SPF}}) = 17290 \cdot (1 - \frac{1}{3.5}) = 12350 \quad (13)$$

According to equation (7), if the heat pump supplied 17290 kWh of thermal energy annually, the following results of renewable energy calculation would be obtained:

$$E_{ERES} = E_{usable} \cdot (1 - \frac{1}{\eta_{SPF} \cdot \eta_{el}}) = 17290 \cdot (1 - \frac{1}{3.5 \cdot 0.455}) = 6433 \quad (14)$$

The results of the analysis showed that the 2013/114/EU method for renewable energy calculation does not take into account the primary energy input for transforming electric power. Therefore, the calculated amount of renewable energy generated by heat pumps is higher than it should be.

Conclusions

All renewable energy sources contain some non-renewable energy and for this reason, the requirement of the 2010/31/EU Directive, stating that more than a half of the amount of energy used by nearly zero-energy buildings should come from renewable energy sources, can only be related to the amounts of renewable and non-renewable primary energy used in the buildings, rather than energy in general, i.e. generated using renewable and non-renewable sources.

The requirement of the 2010/31/EU Directive on the energy performance of buildings to calculate the amount of energy from renewable energy sources for nearly zero-energy buildings following the provisions of the 2009/28/EU Directive is related to the requirement to follow the inadequate equation for estimating the amount of energy supplied by electric heat pumps to a building given therein and in the guidelines 2013/114/EU of the European Commission.

The application of the equation provided in the 2009/28/EU Directive and the guidelines 2013/114/EU results in the ratio values of renewable/non-renewable energy supplied by electric heat pumps to a building that are from 4 to 14 times higher than the values of renewable/non-renewable primary energy ratio.

The ratio Q_{PRr}/Q_{PRn}=1 of renewable/non-renewable primary energy may only be achieved by using highly efficient pumps with η_{SPF} (supplying energy for heating) and η_{EER} (supplying energy for cooling) values fluctuating between 4.8 and 5.2.

Finally, thermal energy is not the only type of energy consumed in buildings as quite large amounts of electric power are used for lighting and ventilation systems as well as various electric installations. Hence, this suggests that merely electric heat pumps will not suffice to achieve the required amount of renewable primary energy in nearly zero-energy buildings. Doing so will require to ensure the supply of energy into a building from other renewable energy sources (solar panels, wind power plants, hydro power plans, biofuel, etc.).

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