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# Can Clean Energy Policy Improve the Quality of Alpine Grassland Ecosystem? A Scenario Analysis to Influence the Energy Changes in the Three-River Headwater Region, China

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**Abstract:** In past decades, ecological services and functions of alpine grassland in the Three-River Headwater Region (TRHR), Qinghai-Tibetan Plateau, have been severely degraded due to overgrazing and overuse of yak dung as a fuel. Therefore, the eco-migration project has been implemented by the national government for improving eco-environmental quality in this region. This paper examines the carbon cycle change from clean energy use of households and assesses its influence on the local grassland ecosystem. Based on the data of household fuels from questionnaire surveys and local statistical yearbooks, we have calculated carbon emission and the ecological benefits by using clean energies. The results showed that total carbon in the process from Net Primary Productivity (NPP) of the ecosystem to dung fuel decreases sharply, and carbon emission from dung is approximate 6% of ecosystem NPP. Reducing the use of yak dung as a fuel has no significant influence on carbon emission, but improves the ecological benefits of the grassland ecosystem, because it is a very important part of the ecosystem carbon cycle. With the most abundant solar energy resources in China, the region should make full use of its advantage for improving ecosystem service values of alpine grassland by making more dung returns to grassland. In conclusion, a clean energy policy (CEP) can effectively improve the ecological services and functions of alpine grassland in the TRHR.

**Keywords:** Three-River Headwater; carbon cycle; alpine grassland ecosystem; energy structure; ecosystem services

## 1. Introduction

Due to the disturbance of human activities, global environments and ecosystems have rapidly changed in the past several decades, and the tendency has been continually worsening [1]. Taking climate warming as an example, the global mean annual temperature has increased by 0.13 °C per decade from 1956–2005 [2]. Additionally, in many regions, especially in vulnerable regions, ecosystem degradation has generated many negative impacts on environments because of unreasonable human activities [3,4]. As the biggest terrestrial system on the Earth, grasslands play an important role in maintaining global environmental quality [5]. In China, grassland ecosystems cover 40% of the national land area, which has a significant role in regulating climate and maintaining terrestrial ecosystem stability [6]. Especially for the world's highest plateau, the Qinghai-Tibetan Plateau is the main source of some major rivers in Asia, such as the Yellow, Yangtze and Mekong rivers [7], and its ecosystem status can directly influence the ecosystem quality of the downstream river systems [8,9]. However, on account of overgrazing and the overuse of yak dung as a fuel in the last few decades, the Three-River Headwater Region (TRHR) in the Qinghai-Tibetan Plateau has been severely degraded, and its service functions, such as water storage, climate regulation, soil and biodiversity conservation, have sharply been decreased [10]. This has led to climate abnormalities, for example, anomalous changes of the heating field intensity and the occurrence of sand storms in China, as well as runoff reduction of relevant rivers in Asia [11,12]. Therefore, in order to improve this critical situation, since 2003, the Chinese government has implemented the eco-migration project of TRHR.

Carbon balance among the land, organisms and the atmosphere plays an important role in regulating ecosystem services [13]. The carbon cycle of the natural world mainly consists of carbon sequestration by plants and other autophytic organisms and carbon release by heterotrophic consumers and decomposers. Carbon can release from various pools by autotrophic and heterotrophic respiration and human activities, such as biomass and fossil fuel burning, land use and land cover change (LUCC) [14,15]. Technological development and demand for fuels and food have disturbed the process of the natural carbon cycle. The disturbance was mainly presented in the carbon emission and carbon sequestration process. The former usually is shown in carbon release accelerated by excessive consumption of biomass and fossil fuels or delayed by using clean energies, such as solar energy, wind energy and tidal energy. The latter is manifest in carbon sequestration speed accelerated by more vegetation cover or delayed by vegetation reduction [16,17]. As for TRHR, overgrazing and burning dung break the carbon cycle laws of its natural ecosystem and then affect its ecosystem service functions [10]. Thus, the major aim of the eco-migration project is to remove those disturbing factors that change the carbon cycle, such as overgrazing and burning dung. In this project, scattered households living by herding in this region had been relocated into planed resettlement areas. All of the migrants were prohibited from practicing grazing and provided with free solar equipment for lighting, cooking and showering purposes to reduce the use of dung energy [18].

Can eco-migration improve eco-environmental problems in the TRHR? What impacts had the project generated on the alpine grassland in the area? Many researchers have conducted research in different aspects around TRHR. Cai *et al.* have analyzed the effects of human-induced and project-induced grassland restoration by the NDVI method [19]. Wang has evaluated the effects of eco-migration on the employment and life of migrants [20]. Zhou and Fu have studied the education situation of migrants in resettling areas [21]. Yi *et al.* have analyzed the impacts of grassland vegetation degradation on soil hydrological and ecological effects [22]. However, the policy about clean energy use of households and its influence on ecosystems of TRHR, such as the carbon cycle and ecosystem services, still lacks scientific research. Therefore, we selected this research theme to study.

Considering the of data on the household energy use situation in TRHR before eco-migration, in this paper, based on the willingness to use clean energy and household current energy situations, we have used energy analysis and a hypothetical scenario method to analyze the impacts of current and future solar equipment use on carbon cycle and ecosystem services of alpine grassland in Guinan County. The data were obtained by household questionnaires, and the available parameters on the alpine grassland ecosystem in Qinghai-Tibetan Plateau were from the literature. In this paper, we aim to reveal the influence of clean energy policy (CEP) for households in resettlement regions on the carbon cycle and the values of ecosystem services in alpine grassland in TRHR, and we hope the conclusions will provide some reference for making or improving the CEP in alpine grassland regions.

## 2. Materials and Methods

### *2.1. Study Area*

Our research was conducted in Guinan County, which is located in eastern Qinghai Province between Xiqin Mountain and the Yellow River, 35°09′–36°08′ N and 100°13′–101°33′ E (see Figure 1).

This county covers an area of 6649.7 km$^2$, where terrain slopes from southeast to northwest. Elevations range between 3000 m and 3500 m, with an average elevation of 3100 m, and the terrain consists mainly of high mountains, flat shoals and river valleys. The region is dominated by herbaceous plants. The grass family (*Gramineae*) and sedge family (*Cyperaceae*) mainly occupy the high mountain, except the main peak, which is covered by weathering clastic rocks. The grass family occurs in flat shoals, and crops cover river valleys. The climate of this area is a typical plateau continental climate, where the mean lowest and highest temperatures in January and July are −11.5 °C and 13.2 °C, respectively. The average annual evaporation is 1412.5 mm, and the average annual precipitation is 398.7 mm; precipitation from June–August comprises more than 70%. Solar radiation is plentiful: 2701 hours annually (h/a) of sunshine duration, 60%–65% of the sunshine percentage and 6299–6660 MJ/m$^2$ of the average annual total solar radiation. The soil is loamy and includes chernozem, chestnut soil, alpine meadow soil, mountain meadow soil, aeolian sandy soil, *etc.*

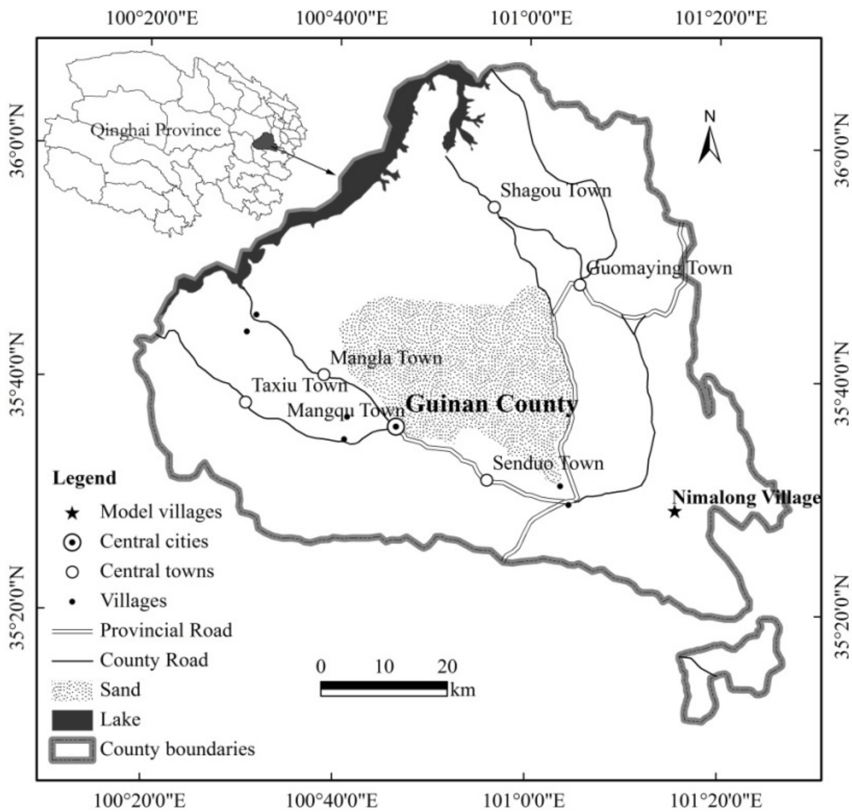


**Figure 1.** The location of Guinan County.

Guinan County, a typical resettlement county, is subordinated to Hainan Tibetan Autonomous Prefecture, Qinghai Province. It consists of 6 towns, which are Taxiu Town, Senduo Town, Guomaying Town, Shagou Town, Mangqu Town and Mangla Town. In 2011, the total population of this county was 77,000 persons, of which rural populations accounted for 58,000. They mainly depended on animal husbandry and crop farming for their livelihood. According to producing and living styles, the 6 towns can be divided into three types, which are the Resettlement Place of Tibetan Herdsmen (RPTH), the Resettlement Place of Longyangxia Reservoir Farmers (RPLRF) and the mixed Resettlement Place of Tibetan Farmers and Herdsmen (RPTFH). The RPTH includes Taxiu Town, Senduo Town and Guomaying Town, where the population of Tibetan nationality is up to 94% of the total population. RPLRF is just comprised of Mangqu Town, where the Tibetan nationality population is only about 34%. RPTFH has Shagou Town and Mangla Town, where the Tibetan nationality population is up to 99.8%. The county has 75 administrative villages, 12,818 households, all of them being resettlement households. The area of available grasslands was 485,700 hm$^2$, constituting 73.08% of the land area in the county. Farming land was 2.919 hm$^2$, accounting for 4.39% of the total land area of the county.

## 2.2. Methodology

The ecosystem quality of alpine grassland is usually indicated by biodiversity, plant height and density, vegetation cover and plant productivity; generally, higher indexes signify a good ecosystem [23,24]. Most of these indexes, however, can be replaced by carbon content. Moreover, the carbon cycle in a region also reflects dynamic change in ecosystem quality. Thus, mapping the carbon cycle process of the ecosystem in the TRHR is an effective way to examine the impacts of CEP on the alpine grassland ecosystem. However, for practical purposes, assessing the change of ecosystem service values is another way to measure the quality of alpine grassland. The two ways are detailed as follows.

### 2.2.1. Carbon Cycle Process of the Ecosystem in TRHR

In the TRHR region, the carbon cycle process of the ecosystem consists mainly of 5 parts as follows: Plants capture carbon dioxide ($CO_2$) by photosynthesis and fix carbon (C). Carbon in a plant body is ingested by livestock, and the rest of C enters the atmosphere by respiring and into the soil by combustion and waste. The C that had streamed into livestock partly goes into the atmosphere by respiring and partly into the bodies of humans via eating, and the rest is excreted by the way of dung. Of the C in dung, some is emitted into the atmosphere by the respiration of microbes; some goes directly into the soil; and the rest goes into the atmosphere by burning as fuel. The soil eventually receives the C from dung and the ash of burned dung, straw and human excretion, and at last, this C is emitted into the atmosphere via soil respiring in the form of $CO_2$. The total carbon cycle can be seen in Figure 2.

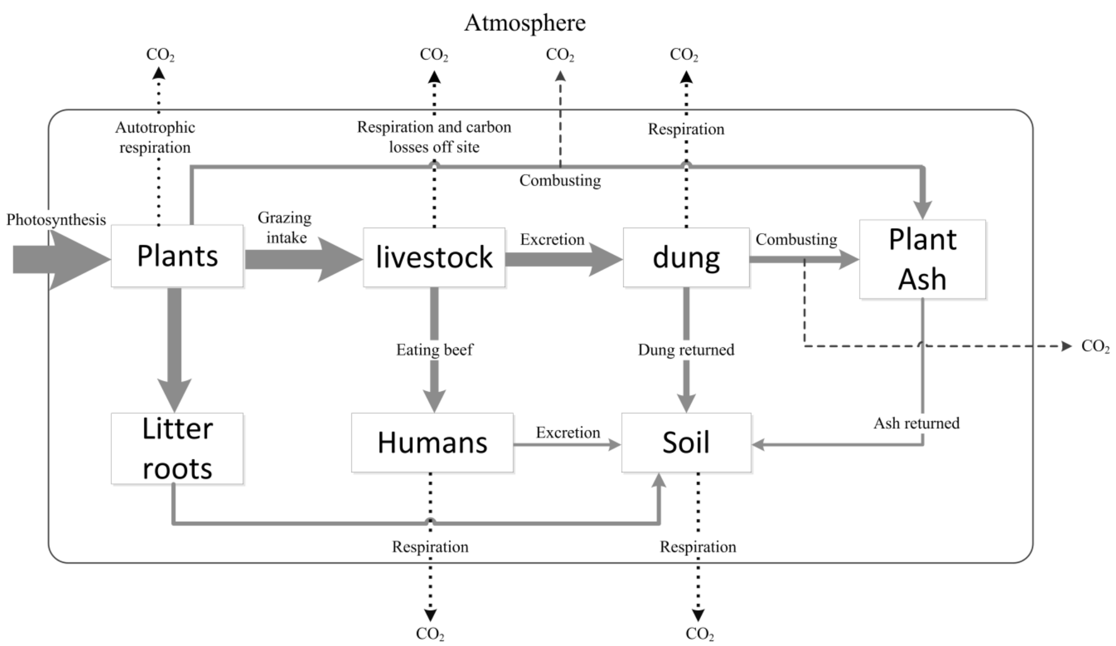


**Figure 2.** Framework of the carbon cycle of the ecosystem in Guinan County.

However, under the CEP, the energy use of households in TRHR had changes largely because of the utilization of solar energy instead of yak dung, which may significantly impact the rate of the carbon cycle [25]. On the one hand, households using solar energy and electrical energy can decrease C emissions by reducing the consumption of biomass fuels, such as straw and dung; meanwhile, more dung returning into grasslands can improve soil quality and strengthen carbon sequestration through the increase of primary production [26,27]. On the other hand, utilization of fossil fuels, such as oil and coal, increases C emissions.

#### 2.2.2. C Budget of the Energy in Guinan County

Based on the above-mentioned carbon cycle process, we try to calculate the C budget of the energy of each segment in the carbon cycle. The computational formulas are listed as below.

In Guinan County, the annual total C emission amount from energy can be calculated through the equations below:

$$Ei = Ri \times Fi \times Hi \times Pi \tag{1}$$

$$Et = \sum Ei \tag{2}$$

where *Ei* is the total C emission from each fuel; *Ri* is the C emission ratio of each fuel (see Table 1) [2]; *Fi* is the weight of each fuel consumption annually per household; *Hi* is the amount of farmer or herdsman households; *Pi* is the percent of each fuel used in different typical resettlement region; *Et* is the annual total C emission amount of energy in Guinan County.

**Table 1.** C emission ratio of various fuels.

| Fuel Type | Electrical Energy | Coal | Oil | Wood | Dung | Straw | Solar Energy |
|---|---|---|---|---|---|---|---|
| Rate of C emission in combustion process | 0 | 0.69 | 0.74 | 0.51 | 0.25 | 0.43 | 0 |

The Net Primary Productivity (NPP) of grassland in Guinan County can be calculated through the available parameters from other research conducted in the alpine grassland ecosystem in Qinghai-Tibetan Plateau. The equation is as below:

$$TNPP = \sum NPPi \times Ai \tag{3}$$

where *TNPP* is the total NPP of Guinan County in g $C/m^2 \cdot a$; *NPPi* is the NPP of grassland, farmland or forestland (see Table 2); *Ai* is the area of grassland, highland barley, rape or forest (see Table 2). The data of the land use were sourced from the annual abstract of the statistics of Guinan County, and the parameters were taken from Xu *et al.* [26] and Zhou *et al.* [28].

**Table 2.** The area and NNP of different land use types. (a means "annually")

| Items | Units | Grassland | Farmland | Forest |
|---|---|---|---|---|
| NNP | g $C/m^2 \cdot a$ | 304.33 | 621.85 | 475.06 |
| Area | $hm^2$ | 471,960 | 23,976 | 16,667 |

The grazing livestock in the county included yaks, goats and sheep. The C intake of livestock will be calculated with the following equation.

$$TCI = \gamma \times (k1 \times C + k2 \times G + k3 \times S) \tag{4}$$

Here, *TCI* is the total C intake of livestock in kg C/a; $\gamma$ is the C content of grass in kg C/kg; $k1$, $k2$ and $k3$ are the amounts of grass intake by cattle, goat and sheep, respectively, in kg; *C* is the cattle number; *G* is the goat number; *S* is the sheep number. The $\gamma$ in the Tibetan Plateau was applied as 0.45 kg C/kg. According to the research for livestock carrying capacity by Yang *et al.* [29], $k1$, $k2$ and $k3$ are applied as 6.17 kg/day, 0.99 kg/day and 1.23 kg/day, respectively. There were 120,471 adult yaks, 96,127 adult goats and 712,057 adult sheep at the end of 2011, according to the annual abstract of the statistics of Guinan County.

Livestock dung is an important carrier for C. There is a fixed ratio between the excretion of livestock and their food intake [30,31]; therefore, we can get the total C of the dung from livestock.

$$Dt = a \times [(1-\theta) \times k \times C + (\mu - 1) \times (k \times G + k \times S) \quad (5)$$

where $Dt$ is total C of dung from livestock in kg C/a; $\alpha$ is the C content of the dung in %; $\theta$ is the digestion ratio of forage in cattle; $\mu$ is the digestion ratio of forage in goats and sheep in %. The $\alpha$ of dung is 30.34% [26]. According to the experiments by Yan *et al.* [32] and by Wang *et al.* [33], the θ and μ were applied as 70% and 60%, respectively.

In Guinan County, yak dung is a significant fuel for households; thus, most was combusted. The annual burned weight of yak dung will be calculated using the equation below.

$$Dc = Pfh \times Wfh + Ph \times Wh + Pl \times Wl \quad (6)$$

Here, $Dc$ is the total weight of yak dung in kg C/a that was burned by household per year in the county; *Pfh*, *Ph* and *Pl* is the household number of the farmers and herdsmen in RPTFH, RPTH and RPLRF; respectively; *Wfh*, *Wh* and *Wl* are the average weight of livestock dung in kg C/a combusted by each household per year in these types of towns.

### 2.2.3. The Current Energy Situations and Household Willingness to Use Solar Energy Based on Household Interview

In order to acquire data about the current household energy situations and willingness to use solar energy, we handed out 190 questionnaires in the middle of July 2012 to households in the resettlement region in Guinan County. Eventually, 147 questionnaires were returned. The content of questionnaires included the use amount for each energy type (including electrical energy, coal, oil, wood, dung, straw and solar energy) and willingness to use different kinds of solar equipment (solar oven, solar water heater, solar electrical appliance and solar warming equipment). Interviewees answered yes or no.

### 2.2.4. The Impact of Non-Biomass Used by Households on the Grassland Ecosystem

The impact of fossil fuels and solar energy used in households on the carbon cycle can be shown through reducing yak dung utilization for enlarging the area where dung is returned naturally into grassland. Thus, the amount of reduced yak dung owing to fossil fuels and solar energy used currently can be estimated as follows.

$$Yt = (EE \times \partial 1 + OE \times \partial 2 + CE \times \partial 3)/\pi \quad (7)$$

Here, $Yt$ is yak dung weight; $EE$, $OE$ and $CE$ are electrical energy, oil and coal used by household now, respectively; $\partial 1$, $\partial 2$ and $\partial 3$ are the conversion coefficients of these fuels changing into standard coal; $\pi$ is the conversion coefficient of yak dung changing into standard coal. $\partial 1$ is applied as 0.32 kg standard coal/kwh electrical energy, $\partial 2$ as 0.714 kg standard coal/kg coal, $\partial 3$ as 1.457 kg standard coal/kg oil and $\pi$ as 0.45.

Nowadays and in the next few years, the total amount of the solar energy that was been and will be used by households in Guinan County can be calculated using the following equation.

$$G_t = \sum_{i=1}^{n} N_i \times \tau_i \times \varnothing_i \times T_i \quad (8)$$

$$G_y = G_t / D_e \quad (9)$$

where $G_t$ is the total energy from various solar energy equipment in J/a, $N_i$ is the total household amount of each type of resettlement region, $\tau_i$ is the percentage of households who were using or will use solar energy, $\phi i$ is the length of the time for each type of solar equipment and $T_i$ is the effective capacity of various solar energy equipment, which were calculated according to the conclusions from Liu *et al.* [34] and Zhu [18] (see Table 3). $G_y$ is yak dung weight, the energy of which equals $G_t$. $De$ is the energy value in J/kg yak dung. The total effective energy of solar equipment used by households now can be calculated through the total hot water amount heated by solar equipment in the whole county as water specific heat capacity (4080 J/L °C), the water temperature heated from 5–100 °C. It is calculated that yak dung can release 13,188,420 J/kg as 1 kg yak dung in energy, being equal to 0.45 kg standard coal (1 kg standard coal can release 29,307,600 J of energy).

**Table 3.** Effective capacity of various equipment for solar energy (kg standard coal).

| Solar Equipment | Units | Annual Effective Capacity |
|---|---|---|
| Solar oven | 1 | 669 |
| Solar water heater | 1 | 351.9 |
| Solar electrical appliance | 100 W | 84.3 |
| Solar warming equipment | 1 | 4884 |

Dung would not be burned as a fuel if solar energy were used by households in the county. According to the conclusion from Xu *et al.* [26], 378.7 kg/hm$^2$· a dung is excreted by cattle if just 1 yak is herded in 1 hm$^2$ of grassland. Thus, the area size where dung as manure naturally comes into grassland can be calculated.

Solar energy equipment instead of dung fuels can improve the grassland ecosystem services in Guinan County, and then, the main ecosystem service functions in this area can produce livestock products, soil conservation, water conservation and carbon fixation [35]. Therefore, this paper has assessed these four service functions. Each service function can be evaluated according to the equations (see Table 4).

**Table 4.** Evaluation system of grassland ecosystem service in three-river source area.

| Index | Methods | Parameters | Refs. |
|---|---|---|---|
| Livestock Products | $T = (O_f - O_u) \times A/k3$ | $T$ is the number of yak added; $O_u$ and $O_f$ are over ground net primary productivity in the case of dung being combusted and returned, respectively; $A$ is the area that dung is returned to grassland for solar energy used; $k3$ is the grass weight that cattle need annually. | [26,36] |
| Water conservation | $W = R \times A \times \theta$ | $W$ is the water conservation amount; $R$ is the amount of precipitation; $A$ is the same as above; $\theta$ is the difference value between the runoff coefficient of the grassland dung returned and not returned. | [37] |
| Soil conservation | $M = A \times S$ | $M$ is the soil conservation amount; $A$ is the same as above; $S$ is the difference between the erosion modulus of the grassland dung returned and not returned. | [38,39] |
| Carbon fixation | $C = A \times (Nr - Nu)$ | $C$ is the total amount of fixed carbon; $A$ is the same as above; $Nr$ is NPP per unit area where dung is returned; $Nu$ is NPP per unit area where dung is combusted. | [26,38,40] |

Notes: $O_u$ = 198.9 g/m$^2$· a; $O_f$ = 231.4 g/m$^2$· a; $R$ = 445.2 mm; $\theta$ = 0.1; S = 300 t/km$^2$· a; $Nr$ = 354.01 g C/m$^2$· a; $N_u$ = 304.33 g C/m$^2$· a.

## 3. Results

### 3.1. The Fuel Situation and Willingness to Use Solar Energy

The survey results showed that every household had similar energy consumption types in each type of resettlement area for RPTFH, RPLRF and RPTH, respectively, but the energy consumption structures of households were very different among the three types (see Table 5). According to the results of survey statistics, in RPTFH and RPLRF, all of the energy types listed in questionnaires had been used, some fuel types by part of families, some by all. In sum, most had a high percentage of utilization. Used dung per household as the main fuel energy was at 5163 kg/a in RPTFH and at 4833 kg/a in RPLRF, respectively. RPTH has a monotonous energy-consumption structure, in which dung is the most important fuel for cooking and warming, with an average amount per household up to 14,100 kg/a. Moreover, popularizing rates of electric energy and dung were up to 100%, whereas other types had low popularizing rates; some were not even used. In sum, the mean use amount of dung per household in RPTH was approximate 2–3-times the other two areas. This is because households in RPTH were mostly herdsmen who still lived by herding.

**Table 5.** Average energy utilization situations in the three types of resettlement regions. RPTFH, Resettlement Place of Tibetan Farmers and Herdsmen; RPTH, Resettlement Place of Tibetan Herdsmen; RPLRF, Resettlement Place of Longyangxia Reservoir Farmers.

| Household Types | Average Number per Household (Mean ± SD) | Energy Type | | Energy Unit | Percentage of Energy Used (%) | Usage Amount per Household (Mean ± SD) |
|---|---|---|---|---|---|---|
| RPTFH | 6 ± 2 | electrical energy | | kw.h/a | 100 | 801 ± 515 |
| | | coal | | kg/a | 100 | 1283 ± 614 |
| | | oil | | L/a | 100 | 315 ± 168 |
| | | wood | | kg/a | 78 | 428 ± 148 |
| | | dung | | kg/a | 100 | 5163 ± 7795 |
| | | straw | | kg/a | 83 | 3516 ± 5497 |
| | | solar energy | solar cooker | hot-water L/a | 48 | 6371 ± 1181 |
| | | | solar water heater | hot-water L/a | 8.7 | 36,000 ± 0 |
| RPTH | 4.3 ± 0.7 | electrical energy | | kw.h/a | 100 | 548 ± 630 |
| | | coal | | kg/a | 20 | 1500 ± 707 |
| | | oil | | L/a | 10 | 300 ± 0 |
| | | wood | | kg/a | 0 | 0 |
| | | dung | | kg/a | 100 | 14,100 ± 3755 |
| | | straw | | kg/a | 0 | 0 |
| | | solar energy | solar cooker | hot-water L/a | 10 | 8760 ± 0 |
| | | | solar water heater | hot-water L/a | 0 | 0 |
| RPLRF | 5 ± 1 | electrical energy | | kw.h/a | 100 | 897 ± 152 |
| | | coal | | kg/a | 100 | 1583 ± 900 |
| | | oil | | L/a | 10 | 2300 ± 1416 |
| | | wood | | kg/a | 83 | 605 ± 314 |
| | | dung | | kg/a | 100 | 4833 ± 1051 |
| | | straw | | kg/a | 100 | 2796 ± 2306 |
| | | solar energy | solar cooker | hot-water L/a | 92 | 10,485 ± 1275 |
| | | | solar water heater | hot-water L/a | 0 | 0 |

In addition, the survey data also indicated that the households that would use solar equipment (including solar oven, solar water heater and solar warmer) accounted for 93.1% of the total visited households, if 60% of the price of solar equipment were subsidized by the government.

## *3.2. The Change of the Carbon Cycle under the Clean Energy Policy*

### 3.2.1. The Situation on C Emission from Fuels in the Ecosystem of Guinan County

According to the data from the questionnaires and the 2011 annual statistical abstract of Guinan County, we calculated the C budgets of the ecosystem. In Figure 3, NPP of plants in the whole county amounted to 1664.5873 kt C/a as calculated by Equation (3), of which grass fixed 1436.3159 kt C/a. In these NPP by grass, 281.9977 kt C/a were consumed by livestock (calculated by Equation (4)). Therefore, we can estimate that the total excreted dung in the county is 100.5903 kt C/a (calculated by Equation (5)). However, yak dung was only 36.6264 kt C/a, accounting for 36.4% of the total. This is because sheep and goats were major species of livestock in the county rather than yaks. Burning fuels is an important C emission source in the TRHR, where the total C emissions from fuels in Guinan

County reached 48.1208 kt C/a according to Equations (1) and (2). Of these fuels, yak dung fuel is a major C emission source, which is 33.4537 kt C/a, up to 69.5% of the total fuels (calculated by Equation (6)). In comparison, C emissions from wood and straw fuels and fossil fuels were much less and only constituted 15.1% and 15.4%, respectively. In sum, biomass fuel is an important C emission source in energy emission, especially for yak dung, although C emission from biomass fuels only constituted 1.8% of NPP in Guinan County.

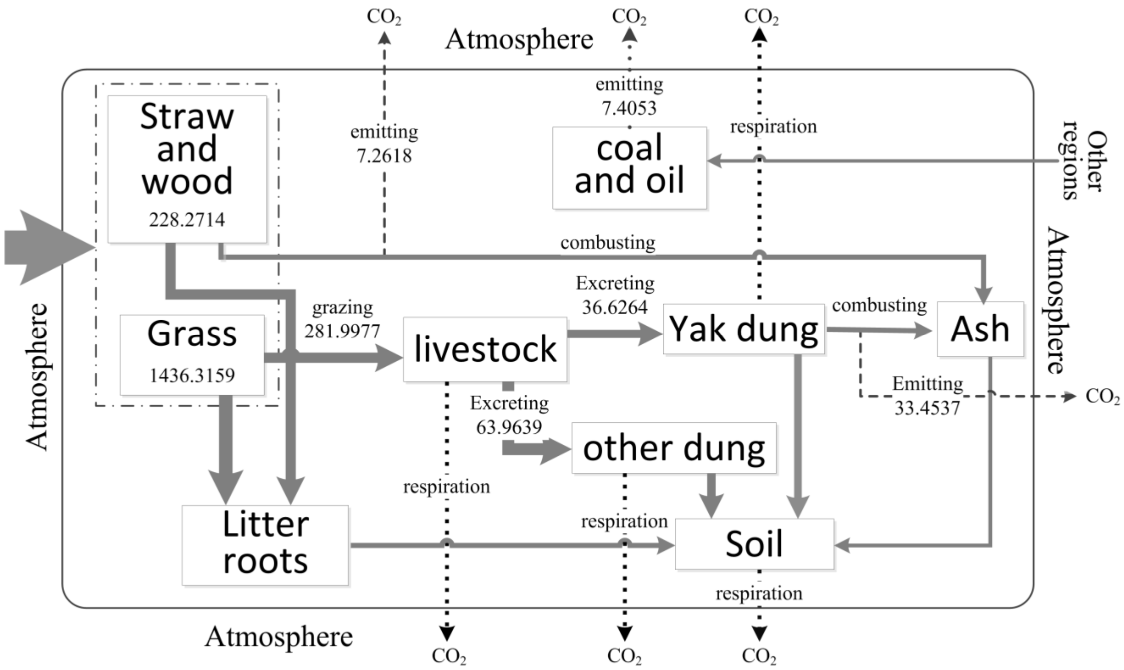


**Figure 3.** C input and output of energy system in Guinan County (kt C/a).

### 3.2.2. The Situation of the C Emission from Fuels in the Ecosystem of Guinan County

Given cooking stoves in resettlement areas are still burning dung in recent years, in this paper, we make the hypothesis that if solar equipment would just replace fossil fuels and reduce the usage of dung fuel rather than other fuels, the savings would be the greatest. Based on the situation in Guinan County, if each household is expecting to use solar energy, which requires a solar oven, a solar water heater, a suite of solar warming equipment and solar electrical appliances, whose total power is 200 watts, the area that yak dung will be returned into grassland will be up to 422,456 $hm^2$ according to Equations (7)–(9). Under these circumstances, the total NPP of the grassland ecosystem in Guinan County would increase up to 1646.1921 kt C/a, which would be 209.8762 kt C/a more than now (see Figure 4). The NPP above the ground will increase by 61.7842 kt C/a. According to 30% of the new increased NPP eaten by livestock, approximately an extra 18.6796 kt C/a will flow into livestock, and it will make 300.6773 kt C/a come into livestock. If the C flowing into livestock is all through yaks eating grass, the excreted yak dung will be 42.2303 kt C/a, increasing by 15.3%. The energy from all the used solar equipment in the county in the near future will be equal to releasing the energy of 71.9865 kt of standard coal, which means 54.7097 kt C/a of emissions from fuels will be reduced. However, yak dung returned into grassland does not greatly decrease C emission in theory, because of C being emitted by respiration or other ways, but it can lower the speed of the cycle.

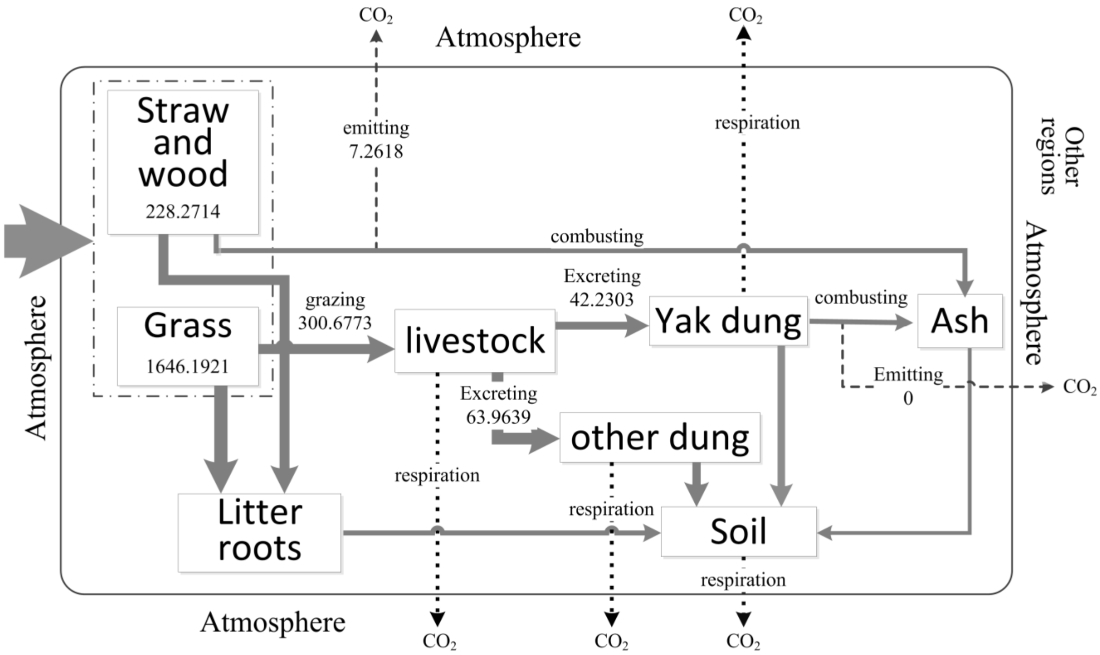


**Figure 4.** C input and output of energy system in Guinan County under the scenario prognostics (kt C/a).

### *3.3. Impacts of the Energy Consumption Structure Change of Households on the Grassland Ecosystem*

#### 3.3.1. Benefits of Grassland Ecosystem from the Consumption of Fossil Fuels and Electrical Energy Today

Combusted fuels had an impact on the carbon cycle of the grassland ecosystem to different extents and in different ways. Yak dung combusted as a fuel can directly change the rate of the carbon cycle in a grassland ecosystem. The grassland where dung is returned has higher productivity than the grassland where it is not returned [28]. The burning of fossil fuels and the utilization of electrical energy are not parts of the carbon cycle of the grassland ecosystem, but they can exert indirect influence on the ecosystem via reducing the use of yak dung. It is calculated that yak dung as a fuel was reduced by 25.2355 kt/a on account of fossil fuels and electrical energy widely used recently as Equation (7), which means that dung was returned normally into 66,643 hm$^2$ grassland without burning disturbance, and 8.6305 kt C/a emission were avoided. However, in fact, used fossil fuels were only reduced by a net of 1.2254 kt C/a, because burned fossil fuels also emitted 7.4053 kt C/a. The dung returned to grassland, however, had improved grassland productivity, adding up to 21.659 kt NPP/a. According to the evaluation methods in Table 5, it can conserve 30,335,887 m$^3$/a of water, keep 199,929 t/a of soil and sequestrate 33,108 t/a of C. The new additional NPP over ground per year can feed 9617 yaks (see Table 6).

**Table 6.** Ecological environmental benefits of grassland from the utilization of fossil fuels, electrical energy and solar energy equipment.

| Functions | Units | Fossil Fuels and Electrical Energy | Solar Equipment Used Nowadays | Solar Equipment Used in Future |
|---|---|---|---|---|
| Feeding livestock | head/a | 9617 | 462 | 60,966 |
| Water conservation | m$^3$/a | 30,335,887 | 1,458,326 | 192,302,043 |
| Soil conservation | t/a | 199,929 | 9611 | 1,267,368 |
| Carbon fixation | t/a | 33,108 | 1592 | 209,876 |

### 3.3.2. Benefits to the Grassland Ecosystem from Solar Energy Equipment Used Today

Solar energy is very common in TRHR, but it was not used until 2005. Solar energy in TRHR was encouraged originally by the free distribution of solar ovens and solar water heaters to local households. Solar electrical equipment and solar warming equipment have also been freely promoted in local households since 2009. However, the solar equipment was still rarely used because, according to our surveys, most households could not operate the equipment and had not developed the habit of using solar power. The used solar energy had produced ecological benefits that can be estimated as Equation (8) and the equations in Table 5. The area that yak dung was returned naturally to the grassland reached 3204 $hm^2$. This is equal to conserving extra water of 1,458,326 t/a, extra soil of 9611 t/a and extra C intake of 1592 t/a, and it is also equal to feeding an extra 462 yaks.

### 3.3.3. Benefits to the Grassland Ecosystem from Solar Energy Equipment Used in Future Years

With solar energy technology developed, the education level of peasant households improved, and with the compensation policy for solar energy equipment, more and more households will use solar equipment for their cooking and warming. The survey showed that 93.1% people were willing to use solar energy. Then, there would be extra 60,966 yaks fed annually, 192,302,043 t/a extra water conserved, 1,267,368 t/a extra soil conserved and 209,876 t C/a fixed (see Table 6).

## 4. Discussion

Although the intention of the eco-migration policy of TRHR is to reduce the negative impacts of human activities on the grassland ecosystem by changing the lifestyle of peasants, in terms of the means of livelihood and fuel types used, the survey results show that grazing was still a main livelihood means for many herdsmen, and yak dung still accounted for the major portion of current fuel consumption. The eco-migration policy of TRHR did not completely reach its expected target. Though the scattered herdsmen were gathered together in a region through the implementation of the project, their lifestyle was not actually altered, because they seldom obtained other occupations and more educational opportunities [41]. Improving cultural opportunities for herdsmen and creating enough non-agricultural jobs should be done to help protect the alpine grassland ecosystem.

Considering the whole county as an ecosystem, this study set out to show C streaming processes from C sequestration by plants to C release from fuels. The processes indicated that little C from the total NPP of the ecosystem was emitted into the atmosphere via combusting straws, wood and yak dung. This is mainly because the special ecosystem only produced fewer biomass fuels, and the low density of population in the region resulted in low demands for fuels. Furthermore, most C was emitted into air by respiration or stocked in soils [42]. As far as each type of biomass fuel is concerned, on account of the little farmland and forest area and the habit of burning dung for their daily lives, the C emissions from the burned straw and wood were much less than from burned dung. In fact, burned dung has also a low proportion in total dung in the carbon cycle, because the dung from sheep and goats is so small in size that it cannot be used as a fuel. Therefore, the high percentage of sheep and goats kept by herdsmen can explain the phenomenon well.

In the process of the carbon cycle, the combustion of biomass fuels may not play a key role in C emissions, because the ratio of C in biomass fuels to total C sequestrated by plants is not high, being less than 2%, but it can exert important influences on the alpine grassland ecosystem. This is because burning yak dung can reduce soil fertility of the grasslands, and *vice versa*, and then reduce or enhance the grassland values of ecosystem services. Thus, using non-biomass fuels instead of biomass fuels can improve the quality of grassland by enhancing the proportion of dung returning to grassland. Compared to burning dung, using fossil fuels in TRHR has little effect on C emission reduction, but it still has produced higher ecological benefits. As for solar energy, its use has many ecosystem benefits, not only reducing C emission from energy, but also enhancing grassland service functions. Obviously, the latter has higher value than the former. Thus, to promote household use, solar energy in TRHR has great significance for improving ecosystem functions.

TRHR is one of the regions that has the richest solar energy in China and even in the world [43]. Therefore, the use-cost of solar energy is lower than in other regions [33]. Based on the willingness of surveyed households to use solar energy and the scenario prognostics of solar equipment used, it is calculated that the area of dung naturally returning to grasslands will be equal to one tenth of the grassland in the county, and reduced C emissions will be equal to the sum from all of the dung combusted now. Therefore, we can gain the conclusion that using solar equipment will make more dung available for the grassland to improve it enormously, especially the alpine grassland ecosystem services' value.

From the conclusions, we can find that the lifestyle of households in TRHR is the most important factor that impacts the alpine grassland ecosystem. In effect, eco-migration just alters their living places in an enforced way, but if their lifestyle and employment are not changed, the aim to improve alpine grassland will not be reached. Thus, the eco-migration policy should consider how to alter the lifestyle of migrants by education and industries, rather than how to migrate and how to prohibit grazing in the future.

In this study, we have calculated the C of NPP of the whole ecosystem in Guinan County based on parameters from others' research, but the C flowed into the livestock, then into dung, and then, C emission from dung depended on statistical data and survey data gathered by questionnaires. However, less surveyed samples and just using statistical mean values of the data may give rise to a result somewhat different from the truth to some extent. In addition, the accuracy error of the results is not avoided due to using different calculation methods from other studies. Comparing conclusions from other researchers, it is reasonable to know the C in each part of the process from NPP to atmosphere in this paper because of the basic consistency with their results.

## 5. Conclusions

In this study, we have found that yak dung is still the paramount fuel in resettlement regions, but solar energy and fossil energy are also being used widely by households. Different types of resettlement regions have a big distinction in the energy consumption structures of households. However, inside of each resettlement region, households have a similar energy consumption type, of which herdsmen households have a more mono-structure than non-herdsmen households. In Guinan County, total carbon in the process from the NPP of the ecosystem to dung fuel is to decrease sharply, and carbon emission from dung is a small part of the ecosystem NPP. With the change of energy types in households, the carbon cycle is also being changed, of which solar energy use has a larger impact than fossil fuel and electrical power. While other fuels are used by local households, grassland ecosystem quality will be improved to some extent due to more dung being returned to the grassland. Solar energy instead of dung fuels used widely in TRHR can exert a remarkably positive influence on the alpine grass ecosystem. Therefore, the solar energy policy will be a very effective way to improve the alpine grassland ecosystem in the Qinghai-Tibetan Plateau if it can be implemented successfully.

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