HIGH MOUNTAIN SOCIETIES AND LIMITED LOCAL RESOURCES – LIVELIHOODS AND ENERGY UTILIZATION IN THE EASTERN PAMIRS, TAJIKISTAN

GEORG HOHBERG, FANNY KRECZI and HARALD ZANDLER

Summary: Energy supply is a key issue in isolated high mountain regions like the Eastern Pamirs of Tajikistan. This study uses an interdisciplinary approach to analyze the energy system of Alichur, an exemplary settlement in the region. Thereby, the local energy mix is evaluated, as well as the current and possible future supply of the two main resources used: Dwarf shrubs and animal manure. Finally, based on the energy system analysis, a locally adapted energy poverty index is developed. In contrast to assumptions made in the literature on the topic, we found that currently only 15% of Alichur's inhabitants are energy poor, 25% are endangered by energy poverty and 60% are energy secure. However, with decreasing access to dwarf shrubs in the future, the share of energy poor households and those endangered by energy poverty may increase to more than 70%, leaving less than 30% of Alichur's households energy secure. In contrast to existing energy poverty indices, the adapted energy poverty index presented here considers social and environmental interrelationships of the case study region. It is therefore well suited for describing the energy situation of Alichur's population.

Zusammenfassung: Die Energieversorgung spielt eine bedeutende Rolle in isolierten Hochgebirgsregionen wie dem Ostpamir Tadschikistans. Die vorgestellte Studie nutzt einen interdisziplinären Ansatz, um das Energiesystem der Ortschaft Alichur stellvertretend für die Energieversorgung im Ostpamir zu untersuchen. Dabei werden sowohl der lokale Energiemix, als auch die gegenwärtige und zukünftige Verfügbarkeit von Zwergsträuchern und Dung als meistgenutzte Energieträger abgeschätzt. Schließlich wird auf Basis der Energiesystemanalyse ein an die lokalen Bedingungen angepasster Energiearmutsindex entwickelt. Im Gegensatz zu gängigen Meinungen in der Literatur wurde mit Hilfe des Energiearmutsindexes ermittelt, dass gegenwärtig nur 15% der Einwohner von Alichur als energiearm, 25% als von Energiearmut gefährdet und 60% als energiesicher gelten. Mit einer zukünftig verringerten Verfügbarkeit von Zwergsträuchern würde der Anteil an energiearmen und von Energiearmut gefährdeten Haushalten jedoch auf über 70% ansteigen, wobei weniger als 30% der Haushalte in Alichur als energiesicher gelten würden. Im Gegensatz zu bestehenden Energiearmutsindices berücksichtigt der vorgestellte Ansatz soziale und naturräumliche Zusammenhänge in der Fallstudienregion. Er ist daher geeignet, die Energiesituation in Alichur adäquat zu beschreiben.

Keywords: Human-nature interaction, Central Asia, mountainous regions, energy poverty, biomass fuels, rural development, degradation

1 Introduction

Within the debate on global development, priority topics such as climate change and sustainable energy use have played a crucial role on the international agenda (cf. SPALDING-FECHER et al. 2005). The relevance of the current debate was highlighted by the United Nations (UN) pronouncing 2012 as the year of "Sustainable Energy for All". Poverty alleviation, the improvement of environmental conditions through reliable access to energy and an increase of renewable energies are important pillars of the UN-resolution, which addresses more than 1.4 billion people who are lacking modern energy supply (UNITED NATIONS 2011). In this context, available research has been focusing on the topics of energy poverty and energy access. However, the analysis of energy poverty remains a complex issue and no generally accepted approach exists. NUSSBAUMER et al. (2011) differentiate between single indicators that show one dimension of a phenomenon or a combination of single indicators assessed within a framework (such as the Millennium Development Goals programme) and composite indicators that aim to investigate more complex, multidimensional issues. One example of a single indicator is the share of household investments for energy, e.g. if more than 10% of the income is spent on energy, the household is considered energy poor (BARNES et al. 2011). SRIVASTAVA et al. (2012) make use of the energy requirements for cooking as an energy poverty benchmark. Another frequently found indicator for ener-

gy poverty is the access to modern energy carriers like electricity or gas (Pachauri and Spreng 2011). Although these may be important factors for energy poverty, they may not be solely decisive (Pereira et al. 2010; Srivastava et al. 2012). The international energy agency uses a set of indicators, such as the share of modern fuels in the energy mix and per capita commercial energy/electricity consumption (IEA 2010). Mirza and Szirmai (2010) use a more complex index that connects energy inconveniences to the shortfall in meeting predefined basic energy amounts. The Multidimensional Energy Poverty Index (MEPI) – a composite indicator showing the deprivation of energy – is presented in Nussbaumer et al. (2011). Thereby, the authors use a set of six indicators to quantify energy poverty: modern cooking fuel, indoor pollution, electricity access, ownership of electric household appliances, ownership of electric entertainment appliances and telecommunication means. Groh (2014) links energy poverty to dependency on biomass, access to credits, energy security, energy quality and degree of remoteness. Obviously, these different approaches result in very diverse outcomes regarding the energy poverty situation. This indicates that, even though these energy poverty indices might produce valuable results for the regions assessed, they cannot be employed universally for other regions with varying living conditions (cf. Barnes et al. 2011; Katsoulakos 2011; Pereira et al. 2010; Srivastava et al. 2012).

As combating energy poverty in mountain regions is of paramount importance (Katsoulakos 2011), the associated analysis and identification of central elements involved is not trivial. The Eastern Pamirs of Tajikistan are a prime example of a mountain region in which energy poverty issues are crucial for sustainable development. Droux and Hoeck (2004) mention a "severe energy crisis" in the region due to a lack of energy access. Furthermore, Förster et al. (2011) highlight that energy supply plays a major role for the reduction of vegetation degradation and poverty in the Pamir-Alai Mountains. More recently, Kraudzun et al. (2014) investigated the status of dwarf shrubs (*Krascheninnikovia ceratoides*, *Artemisia spec.*), which are strongly linked to energy access as a central thermal energy source in the area, and concluded that thermal energy use and supply are highly diversified. Kraudzun (2014) emphasizes the role and increasing importance of animal manure as another locally available energy carrier and provides an overview of the dynamic energy transformation in the region. All these studies analyze aspects of energy poverty based either on a limited database or

offer only confined insights into the energy system of the Eastern Pamirs. Reliable energy consumption and provision figures are still missing, despite their relevance to understand the current and future energy situation in the region. Additionally, a comprehensive, in-depth methodology that contrasts energy demand and supply based on the background of local socio-economic conditions is also lacking. However, the energy situation of the Eastern Pamirs varies with diverse local conditions in the region's villages and cannot be assessed with the described existing measures of energy poverty on a larger scale. Therefore, an adapted energy poverty index based on an interdisciplinary survey may be more suitable.

In order to meet this objective, we analyze the energy system of the medium sized Eastern Pamir village of Alichur. Based on a profound dataset, we develop a methodology to specify the local energy situation in the case study village. The approach intends to bridge the gap between generalized quantitative energy poverty indices on the one hand, and specific qualitative surveys on the other hand. Although all or nearly all households of Alichur are expected to be classified as energy poor using existing single indicator energy poverty indices, there is strong evidence that a more detailed consideration of the local energy consumption patterns yields a more diversified picture (Kraudzun 2014). Furthermore, despite very pessimistic projections regarding available energy ten years ago (Droux and Hoeck 2004), the present energy situation in the Eastern Pamirs appears relatively stable. Therefore, a locally adapted energy poverty index is considered to be more suitable than existing methods to clarify specific questions regarding the current and possible future energy security in the case study region and is used to evaluate the following two hypotheses:

1. The greatest share of households in the village can supply themselves with enough energy to satisfy their current energy demand and even possess sufficient resources to cope with shocks to the social or energy system.

Especially dwarf shrubs and animal manure currently provide relevant shares of the local energy mix at low costs (cf. Kraudzun 2014) and a considerable number of publications (i.e. Achmadov et al.; 2006; Breckle and Wucherer 2006; Hoeck et al. 2007) highlight the importance of dwarf shrubs for the current energy supply of the Eastern Pamirs and at the same time report alarming figures about their degradation. This leads to the second hypothesis of this study:

2. If local dwarf shrub stands are being depleted, the energy security of the local inhabitants is likely to worsen significantly in the future.

By analyzing an energy system exemplary for the Eastern Pamirs, this study aims at clarifying whether or not the energy crisis described in literature is based on scientific local evidence.

2   Study area

This paper analyses the energy system of Alichur, a village located in the autonomous province Gorno-Badachschanskaja Avtonomnaja Oblast (GBAO) of the Central Asian Republic of Tajikistan. GBAO covers the whole Tajik part of the Pamir Mountains. It consists of seven administrative districts (*rajons*) and one urban region. Alichur is located in the *rajon* Murghab whose administrative center is the city of Murghab. The *rajon* of Murghab is further subdivided into six departments (*jamoats*). The village of Alichur is the center of the *jamoat* Alichur, which also includes the villages of Bash Gumböz and Bulunkul and their surroundings (Fig. 1). Alichur has 1,295 inhabitants (January 2013), consisting of 314 families that are dis-

tributed between 210 separate households in the village and some further households (i.e. pasture camps and road maintenance stations) in the near surroundings. Seventy-six percent of the population are ethnic Kyrgyz and 24% are Pamiri (Shia Ismaili Mountain Tajiks, STATDAT. JAMOAT ALICHUR 2013).

According to our household survey data, the average income of people in Alichur is 155 USD per month, including official salaries, pensions, formal seasonal work and self-employed businesses. The state is the main source of monetary income: 44% of formal incomes are official salaries of which 47% are pensions. Apart from monetary income, livestock as transformable financial capital plays a great role for sustaining livelihoods in the Eastern Pamirs (cf. KRECZI 2011). The average livestock per household in Alichur is 23.1 units of small livestock (goat and sheep) and 5.5 units of big livestock (yak and cow) according to the 2013 household interviews. The Pamir Highway (M41) which passes through the village has played a crucial role in the development of the village. This main road, connecting the centers and markets of Khorog in the Western Pamirs and Osh in Kyrgyzstan, is still an important feature for livelihoods in Alichur and influences utilization patterns
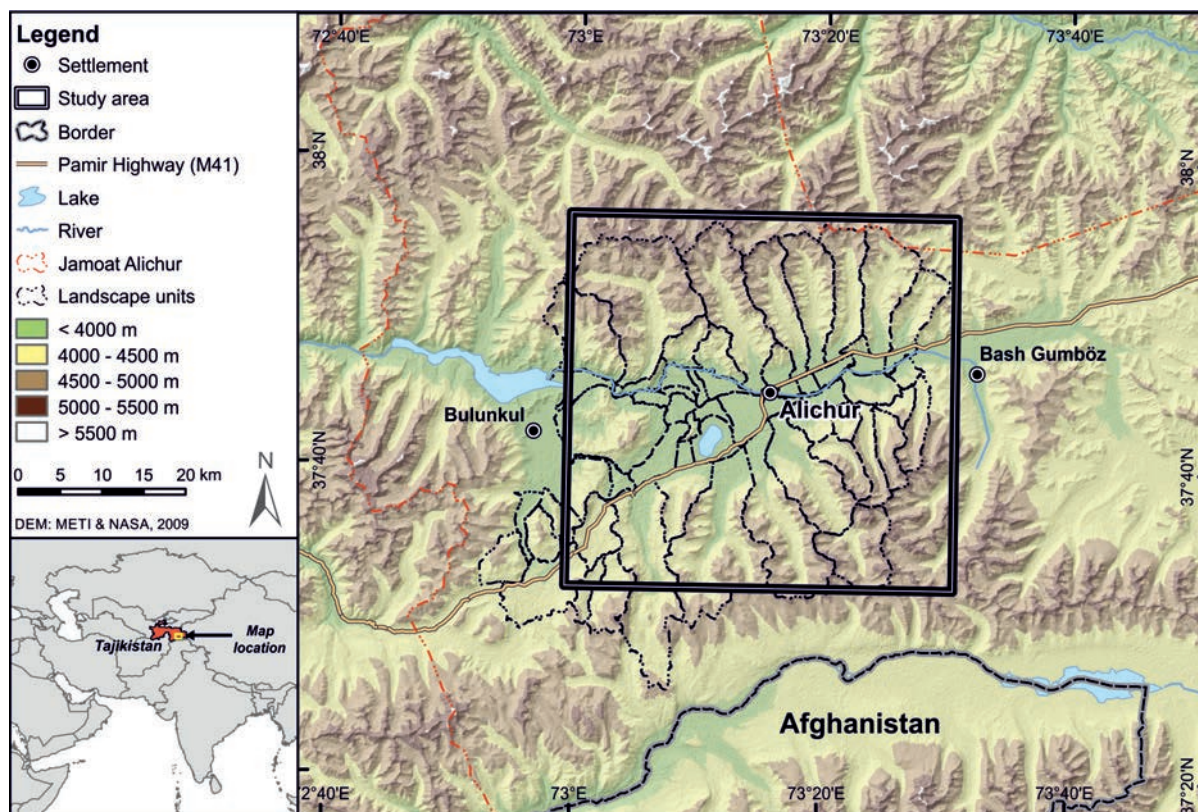

Fig. 1: Location of the study area. Area is delimited according to the availability of satellite data used for the biomass model

of local resources, which have to be transported from the periphery to the settlement.

The climate of this high mountain plateau can be characterized as cold and dry (Bulunkul annual means 1999–2012: -6.1 °C, 95 mm, Tajik Met Service 2013). Scarce dwarf shrub dominated vegetation adapted to this harsh environment is characteristic for all areas except azonal vegetation sites in riverbeds and high altitudes with good water provision. Due to the absence of trees, dwarf shrubs (*Krascheninnikovia ceratoides, Artemisia spec.*) are the only locally available woody biomass. Thereby, the largest share of the plant's biomass is located underground in the root zone. We will refer to these dwarf shrubs as *teresken (Krascheninnikovia ceratoides)* and *shyvak (Artemisia spec.)* in this study, as these are their locally known Kyrgyz names.

3   Methods

This study uses an interdisciplinary approach, incorporating qualitative and quantitative, geoecological and social data, to investigate the complex phenom-enon and the various forms of energy poverty and follows two main methodological approaches: The analysis of the local energy system of Alichur and the development of a locally adapted energy poverty index. On the energy consumption side, household interviews combined with a thermal analysis of commonly utilized energy carriers yield quantitative data on the current energy-mix. On the supply side, the capacity of the local energy carriers - animal manure in processed form (local: *kuik*) and air dried dropings (local: *tezek*) as well as dwarf shrub biomass - are investigated in order to identify possible future developments of the energy system. A map of all available harvesting areas allows a spatial assessment of the current and anticipated future biomass supply. Following the analysis of the local energy system, a regionally adapted energy poverty index is derived (Fig. 2). For the development of this localized energy poverty index, qualitative and quantitative social data was used in different steps. Environmental data and its interpretation are incorporated again when projecting future scenarios. The index will be used to assess the present energy poverty situation at the local level and to identify possible future trends.
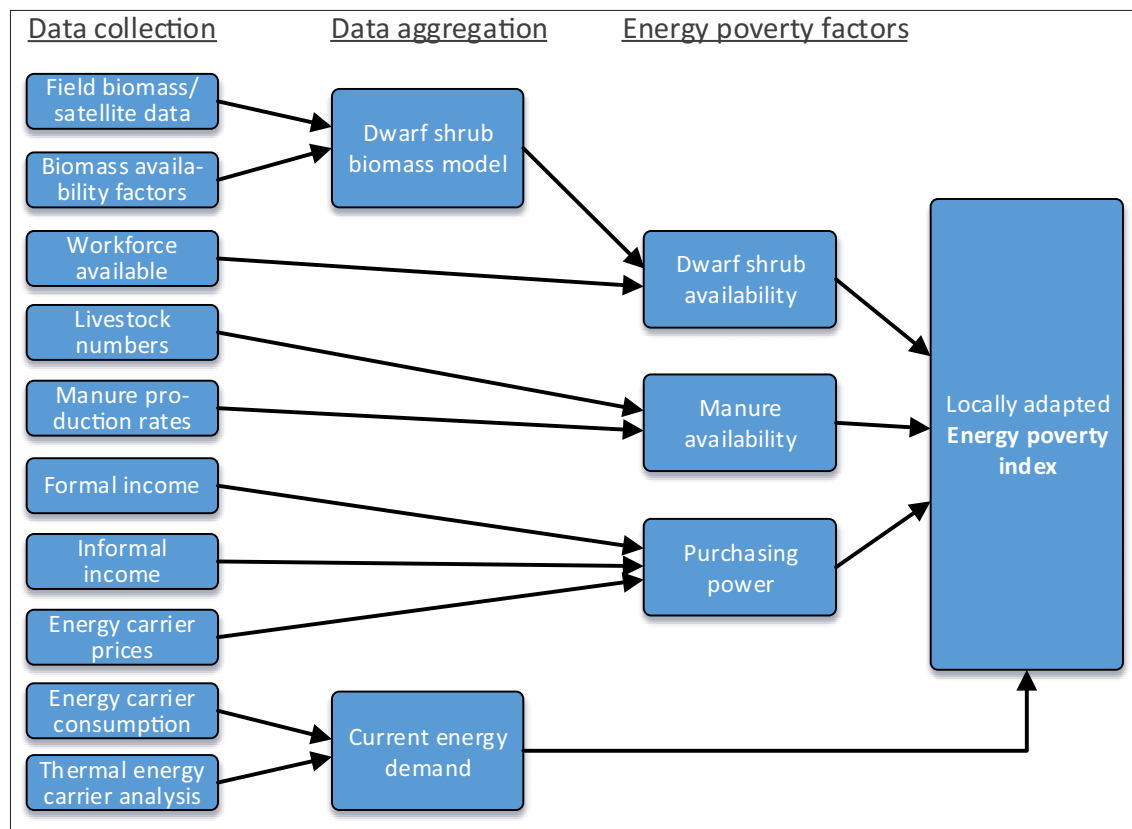

Fig. 2: Steps to a locally adapted energy poverty index for Alichur

3.1 Analysis of the local energy system

3.1.1 Household interviews and spatial allocation

In March 2013, a comprehensive survey on the 2012 energy utilization was conducted among private households of Alichur. On the one hand, data related to demand, acquisition and consumption of local energy and, on the other hand, information about the demographic structure, living conditions and livelihood strategies of households was collected. Additionally, the spatial characteristics of local dwarf shrub biomass harvesting were analyzed. In total, 210 households were counted and visited in the village. 119 households were available for the interview. Following a test phase, which aimed to improve the questionnaire regarding structure and formulation of questions, six local assistants conducted the interviews in pairs. The interview partners represented both Kirghiz and Pamirian ethnic groups respectively. In doing so, the willingness to share information among the interviewees was increased and translation errors were minimized. Asked for amounts of energy carriers used, interviewees typically answered in units of purchase or acquisition. Specifications for masses of coal were, without exception, made in metric units such as tons or kilogram. Yet, locally generated energy carriers were mainly specified in regional units such as bundles of dwarf shrubs or different types of lorry loads of animal manure and dwarf shrubs (cf. Mislimshoeva et al. 2014). In order to convert these regional units to metric units, 57 samples of dwarf shrub bundles were measured. The lorries' cargo capacity was determined by measuring the bed area as well as the bed height or the height of additional installations. In addition, two cargo density samples were each recorded for *kuik* and for dwarf shrubs. Derived conversion factors are valid for the case study of Alichur and cannot directly be transferred to other villages of the Eastern Pamirs as harvesting habits vary significantly in the region. More details on the derivation of the conversion factors are presented in Hohberg (submitted). To improve the comparability between different types of energy carriers, thermic analysis of one representative sample of *tereken*, *shyvak*, *kuik* and *tezek* was carried out at the Institute of Combustion and Power Plant Technology, University of Stuttgart (IFK 2013). In addition to the quantitative data set, qualitative household interviews were conducted in 2013. Information concerning social aspects influencing utilization patterns, organization and acquisition

of local fuels, as well as the demand for resources was collected in semi-structured, biographical and guided expert interviews. Qualitative data served not only to complement and triangulate quantitative data, but to gain an in-depth understanding of the local energy system and living conditions, which evoke complex coping mechanisms of households. Furthermore, qualitative data played a crucial role for the deduction of the different categories that the energy poverty index is based on. The values for classification within the different categories, as well as class limits, are based on quantitative data.

To allocate biomass amounts mentioned in the interviews, a classification of the territory into landscape units was necessary. Borders used for this classification process were pasture areas and landmarks such as ridges, rivers or roads. An iterative process was employed using a digital elevation model (DEM, METI and NASA 2009), information of the local community with subsequent validation and a geographic information system (GIS) (Fig. 1).

3.1.2 Manure production and dwarf shrub biomass availability and access

Based on data from the 2013 household interviews and the local veterinary, livestock numbers assigned to the village of Alichur were estimated. Daily manure production figures of relevant livestock species were estimated through the field survey and expert interviews and validated by literature data (Breu 2006; Chambers 2001; Kadian 2002). Finally, *kuik* production figures were estimated by multiplying the total manure production of a livestock species by the share of time it spends in a shed. *Tezek* production numbers equal the total manure production of big livestock subtracted by its *kuik* production.

The methodology to assess dwarf shrub biomass availability incorporates the application of a spatial biomass model and the definition of scenarios considering realistic limiting factors for calculation of available biomass. The development of the spatial biomass model was performed using RapidEye (RapidEye AG 2009), Landsat OLI (USGS 2013) and ASTER DEM (METI and NASA 2009) satellite images. The methods, data and the best performing model of Zandler et al. (2015) were applied, but modeling was restricted to the 20 highest ranking remote sensing variables according to the importance assessment therein. As empirical models are

always connected to modeling errors, respective restrictions were introduced to avoid overly optimistic biomass predictions. Zᴀɴᴅʟᴇʀ et al. (2015) state that better performing biomass models showed an RMSE of approximately 1,000 kg/ha under the given research conditions. Therefore, this value was subtracted from all predicted biomass values in this study to provide a conservative assessment of biomass availability. Resulting negative values were set to zero. To take aforementioned realistic limiting factors related to dwarf shrub harvest into account, field observations and interviews were used to develop different scenarios. Generally, two different dwarf shrub harvesting practices can be distinguished: harvesting on foot or donkey, referred to as *individual harvest* herein, or *motorized harvest* in pairs or groups using available vehicles. Furthermore, harvesters only excavate dwarf shrubs in regions where a certain minimum biomass amount is available. Areas with biomass densities below certain thresholds are usually not harvested even though they are easily accessible and frequently found near villages. Therefore, in Scenario 1, harvest takes place only in areas with more than 500 kg/ha and the biomass was set to zero in all areas below this level. In Scenario 2, the harvesting threshold was raised to 1,000 kg/ha to allow for a natural variability of worthwhile harvesting area selection. These thresholds are especially important when it comes to modeling *individual harvest* by foot or donkey. *Individual harvest* is restricted to a walking distance of 90 minutes around the village of Alichur, a value above which travel times do not allow for a daily return to Alichur from the harvest area. Due to the comparably high transportation effort and cost and a generally larger number of involved harvesters, *motorized harvest* is only conducted in areas with higher quantities of biomass available. Therefore, two additional scenarios with higher thresholds, one with a 1,500 kg/ha (Scenario 3) and another with a 2,000 kg/ha (Scenario 4), were calculated.

Besides availability, accessibility to dwarf shrub biomass is instrumental for its utilization. To access more remote dwarf shrub areas for harvesting, former Soviet lorries, remnants of Soviet times, are used in Alichur. The model GAZ-66, which is an all-terrain Soviet military lorry that can drive on inclinations of up to 30° when unloaded (NTIS 1973), is the lorry most frequently utilized for these purposes. However, when used for harvesting, these lorries are loaded up to two meters high with dwarf shrubs and the maximum passable inclination is lower so that a maximum drivable inclina-

tion of 20° is assumed. A DEM (METI and NASA 2009) was employed to identify areas with inclinations lower than or equal to 20° in the study region. Additionally, a shapefile of the local road network in Alichur district and one of all water bodies in the region were used for evaluation of dwarf shrub accessibility. All areas that are not covered by a water body and connected to the village of Alichur by road or are accessible from Alichur by passing only areas with inclinations lower than or equal to 20° are evaluated as accessible by motorized vehicle. In total, 85,700 ha are accessible by motorized vehicle in the project region.

3.2 Local energy poverty index

Animal manure and dwarf shrub biomass are identified as crucial for the energy supply of households in the case study village of Alichur. Therefore, a household's livestock ownership (access to manure) and available workforce (harvest of dwarf shrubs) are key factors determining energy security. As a matter of course, monetary income can compensate both of these two factors. In order to assess the energy situation of the households, the availability of the aforementioned factors of workforce, livestock possession and monetary income is quantified on the household level into the three categories of *sufficient quantity*, *medium quantity* and *low quantity*. In this context, *sufficient quantity* corresponds to a factor's capability to provide 100 % or more, *medium quantity* to provide 50 % to less than 100 % and *low quantity* to provide less than 50 % of the annual average energy demand. Livestock ownership, being a substantial part of a household´s tied up financial capital in the Eastern Pamirs (Kʀᴇᴄᴢɪ 2011), is not taken into account within the calculation of monetary income. In order to consider a household's situation as energy secure, at least one of the described key factors must be available at a *sufficient quantity* and a second factor at a *medium quantity*. An energy secure household is able to satisfy its total energy demand and can cope with shocks, trends and seasonal changes. Households that have one of the factors at *sufficient quantity* or two factors at *medium quantities* are considered to be endangered by energy poverty. Though these households are currently able to satisfy their energy demand, they are vulnerable to changes in the livelihood system. Finally, energy poor households cannot supply themselves with sufficient energy carriers, are relying on external help and/or complex bundles of survival strategies.

4   Results and discussion

4.1 The local energy system of Alichur

With five out of the 119 interviewed households giving contradictory statements about their energy consumption, 114 valid datasets resulted from the survey (54 % of all households). The masses of resource consumption resulting from these household interviews are depicted in table 1 together with heat of combustion figures resulting from thermic analysis (IFK 2013).

We found that households in Alichur consumed on average 161.7 gigajoules (GJ) of energy in 2012 (Fig. 3). Ninety point six percent of this consumption is provided by the local resources of manure, dwarf shrubs and – to a very small extent – by decentralized solar power (households having little solar panels on their roofs). The energy utilized from manure amounts to 84.7 GJ per year and makes up around 52.4 % of the total energy consumed per household. Both *kuik* and *tezek* were used by the inhabitants of Alichur. Yet, *kuik* was reported to be responsible for energy generation of 78.7 GJ per household (48.7 % of the total energy mix), while *tezek* only provided 6.0 GJ (3.7 % of the total energy mix). On average 6,047 kg *kuik* and 396 kg *tezek* were used per household. Sixty-one point one GJ per household was generated by burning dwarf shrubs, which translates into 37.9 % of the energy mix and is equivalent to 3,367 kg dwarf shrubs. People reported that they generally had no preferences for *tereseken* or *shyvak* and used either one depending on which was more easily accessible. Solar panels deliver no more than 0.6 GJ per household and year, about 0.4 % of the total energy used. In 2012, 9.3 % of the total energy mix (15.1 GJ or 655 kg) was provided by coal, the only external energy carrier imported to Alichur for room heating.

These findings show some similarities to HOECK et al. (2007) and MISLIMSHOEVA et al. (2014) who studied energy consumption in settlements of the Western Pamirs. They indicate that the largest share of energy consumed was met by local biomass. Yet, energy demand from biomass was mainly satisfied by dwarf shrubs according to HOECK et al. (2007) and by animal manure according to MISLIMSHOEVA et al. (2014). This is different to our work where the energy carriers of animal manure and dwarf shrubs account for approximately equal shares of the energy mix, underlining strong regional differences in energy utilization (cf. KRAUDZUN 2014). Our study is the first to analyze dwarf shrub consumption on a more extensive database in this region. With a total consumption of 3.4 t of dwarf shrubs per household and year, our findings range between the 1.2 t given by WIEDEMANN et al. (2012) and 7.9 t given by DROUX and HOECK (2004). These studies derived their figures from a much smaller sample. The resulting total energy consumption of 161.7 GJ per household and year with an average of 5.06 persons per household is rather high as compared to the Tajik average, which is 18.1 GJ per person (91.6 GJ per 5.06 persons) (BREU and HURNI 2003). Regional references state figures between 69 GJ and 140 GJ in the Western Pamirs (HOECK et al. 2007; MISLIMSHOEVA et al. 2014). As energy demand may increase due to bad energy infrastructure (HOECK et al. 2007), increasing elevation (MISLIMSHOEVA et al. 2014) and lacking access to energy grids, our results are within a plausible range.

Keeping the overall energy mix of Alichur in mind, the focus of this research is on the most important local energy carriers of manure and dwarf shrubs. We estimated the total livestock numbers of Alichur at 1,500 yaks, 200 cows, 2,000 goats and 2,900 sheep. Milk-yaks, young yaks and few bulls are kept in the shed during night time (VANSELOW 2011). The remaining yaks, approximately 50 %, are

Tab. 1: Average resource consumption figures of Alichur and heat of combustion of selected energy carriers used in Alichur

Energy Carrier	*Tereseken*	*Shyvak*	*Kuik*	*Tezek*	Coal
Average amount consumed per year and HH	1,343 kg	2,024 kg	6,047 kg	396 kg	655 kg
Standard deviation of the amount consumed per year and HH	1,798 kg	1,532 kg	2,786 kg	817 kg	615 kg
Heat of combustion [MJ/kg]	17.8	18.5	13.0	15.2	23.0

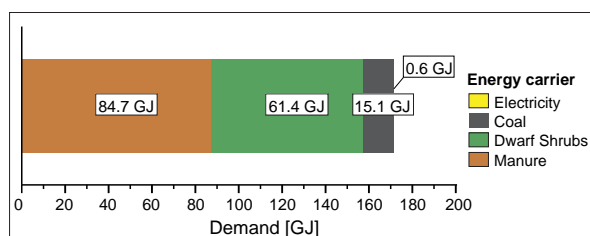Source: Own samples kindly analyzed by Institute of Combustion and Power Plant Technology (IFK) in Stuttgart

Fig. 3: Average primary energy consumption of Alichur households in 2012

left to graze day and night. Small livestock as well as cows are kept in sheds during the night in summer and winter. Therefore, it is assumed that 25 % of the yak droppings and 50 % of sheep, goat and cow droppings accumulate in sheds and are the source of *kuik*. Due to the droppings' consistency, only yak and cow manure can be collected from the pastures for use as *tezek*. Assuming all can be collected, these account for 75 % of the produced yak manure and 50 % of the cow manure. Estimated figures consider a moisture content of 7 % for *kuik* and *tezek*. This value was evaluated for air dried *kuik* and *tezek* from Alichur by IFK (2013). Table 2 gives *tezek* and *kuik* production figures per head and year. Multiplying the livestock figures derived with the manure production figures we calculated a potential *kuik* production capacity of 889 t per year and a potential *tezek* production capacity of 1,558 t per year in the vicinity of Alichur.

With a calculated *kuik* production capacity of only 889 t and an estimated total *kuik* consumption of 1,260 t, clearly all available *kuik* was utilized in 2012 in Alichur and additional imports from neighboring areas were required. In contrast, only around 80 t of *tezek* were used by the households of Alichur, where the production of *tezek* during this year was around 1,558 t. This amounts to only 5 % of the theoretically available *tezek*.

In total, 789 t of dwarf shrubs were harvested in the vicinity of Alichur in 2012. Out of these, 82 t were exported from the region, 707 t were used by the inhabitants of Alichur themselves. Dwarf shrub harvesting activities in 27 *landscape unit*s were conducted (Fig. 4). This includes 76 % of all *landscape units* bordering the Pamir Highway (19 out of 25) and 44 % of all identified *landscape units* (27 out of 61). Depending on the selection of the harvesting sites, different means of transport are required: *Individual harvest* is practiced within walking distance from the village center. HOHBERG (submitted) derives a cost distance raster for individual harvest around Alichur, which is based on empirical field data. He considers a walking distance of 90 minutes around Alichur as a maximum

range for individual harvest. The resulting area for individual harvest is used in this work (red outline in Fig. 4). *Motorized harvest* takes place preferably along the Pamir Highway at medium distances of around 25 km away from Alichur and to a smaller extent also in areas not accessible from the Pamir Highway.

Regarding biomass availability, cross validated error measures of the spatial biomass model resulted in a bias of 47 kg/ha, a RMSE of 910 kg/ha and a relative RMSE of 54 %, showing a similar performance compared to remote sensing based biomass quantification studies in other regions (ZANDLER et al. 2015). Predicted areal mean biomass of the conservative model including the whole area (Fig. 4) was 921 kg/ha. Spatially, lowest amounts were predicted at summit areas, in the Alichur Valley at lower elevations, in the vicinity of Alichur and near main roads. Highest amounts were predicted for slopes of northerly and southerly reaching side valleys with the maxima at valley ends at higher altitudes. Total predicted dwarf shrub biomass for all *landscape units* ranged from 153,522 t (Scenario 2) to 164,503 t (Scenario 1). Reachable biomass for *individual harvest* by foot or donkey varied from 8,343 t (Scenario 2) to 10,080 t (Scenario 1). Regarding accessible biomass by vehicle (*motorized harvest*), the amount of dwarf shrub ranged from 63,821 t (Scenario 4) to 75,479 t (Scenario 3). These results indicate that, although accessibility is an important issue, biomass availability is still high in the surroundings of Alichur, which contradicts the findings of DROUX and HOECK (2004), who provide evidence of an alarming energy situation due to the rapid decline of dwarf shrub vegetation in the region based on biomass estimates. However, this is the first study to analyze biomass availability in this region based on empirical data, in contrast to existing rough estimates. Furthermore, our findings are supported by the more recent work of KRAUDZUN (2014) and KRAUDZUN et al. (2014), who state that the situation is more complex and that intact dwarf shrub vegetation may commonly exist side by side with degraded areas. In accordance with this, our spatial distribution of modeled biomass (Fig. 4) shows no or low biomass amounts near the Pamir Highway in comparably easily accessible regions, but high biomass quantities at a certain distance from these main routes, but still in the vicinity of Alichur. All these figures only depict the present day available biomass amounts that could be exploited under the given assumptions, without considering sustainable development or

Tab. 2: *Tezek* and *kuik* production figures of relevant livestock species

	Sheep	Goat	Cow	Yak
Tezek	--	--	970 kg/a	909 kg/a
Kuik	49 kg/a	49 kg/a	970 kg/a	303 kg/a

other mechanisms that may influence dwarf shrub utilization. To assess long-term impacts of harvesting on biomass and therefore energy availability, figures on regeneration of dwarf shrubs are very important. As these plants are extremely slow growing (WALTER and BRECKLE 1986), comprehensive studies on this issue were not possible during our work, although observations of a few disturbed areas (n=5) indicate that regeneration takes place at a rate of about 14–39 kg/ha*a. With dwarf shrubs growth figures of 20–30 kg/ha*a (WALTER and BRECKLE 1986), 70 kg/ha*a (CLEMENS 2001), 30-70 kg/ha*a (max. 150 kg/ha*a) (BRECKLE and WUCHERER 2006) in the literature, our measurements appear rather conservative.

A comparison of the harvested and modeled biomass on the subject of accessibility shows a general agreement in their distribution, as in most cases highest amounts were harvested in regions where high amounts of biomass are accessible. However, there are some discrepancies especially in the southwestern *landscape units* along the Pamir Highway, where harvesting amounts were high but available biomass was low according to the model. This may be partly explained by errors in the model, but may also result from clouds in the satellite images in those regions, which led to zero modeled biomass. Finally, results of the regional biomass model have to be interpreted carefully, as remote sensing based methods are limited in this environment and errors are relatively large (ZANDLER et al. 2015).

4.2 An energy poverty index adapted to the local situation of Alichur

Through the energy-system analysis performed, it becomes clear that none of the existing energy poverty indices initially mentioned adequately reflect the energetic situation of Alichur. Setting an energy poverty threshold based on the share of monetary income households spent on energy carriers (i.e. 10 % as mentioned in BARNES et al. 2011) neglects the importance of local biomass like dwarf shrubs and *kuik* in the energy system investigated. Similarly, as no household in Alichur is

connected to the electricity or the gas grid simply because these do not exist, access to modern energy carriers as suggested by IEA (2010) cannot serve as an energy poverty index in Alichur. Furthermore, the composite index presented in NUSSBAUMER et al. (2011) is not able to differentiate between households in Alichur, as either all or none of the indicators apply to every household. This situation is comparable when considering other energy poverty indices as well (e.g. GROH 2014) and thereby supports the necessity of a locally adapted energy poverty index.

During the energy system analysis, we identified access to the three energy carriers of *kuik*, dwarf shrubs and coal as being critical for satisfying people's demand for heating and cooking (Fig. 3). For the energy index developed, we focus on people's ability to purchase energy carriers and to supply themselves with dwarf shrubs at minimum cost (or nearly free of charge). Due to the fact that *kuik*, in contrast to coal, is available all year round and can be purchased at considerably lower costs in comparison to coal, it serves as a measure for the amount of energy that people are able to purchase in our energy poverty index. When considering coal consumption besides donations by the Red Cross, commercial coal is currently consumed by wealthier households in Alichur only. These households use coal regardless of its higher price because of its convenience in comparison to *kuik* and dwarf shrubs. Coal therefore does not influence energy poverty and is not directly included in the energy poverty index.

We observed that, in regard to its calorific value, *kuik* was the cheapest energy carrier available in Alichur. On average the price of one ton of *kuik* was 41 USD in 2012. In order to cover an energy demand of 161.7 GJ, 12.3 t of *kuik* are needed. At the given price this requires 504 USD (252 USD to cover 50 % of the energy demand). In 2012, the interviewed households on average spend 17 % of their monetary income on energy, though the standard deviation was 19 % and thus rather high. It is assumed that no more than 36 % (the average plus one standard deviation) of a household's income can be spent on energy carriers.
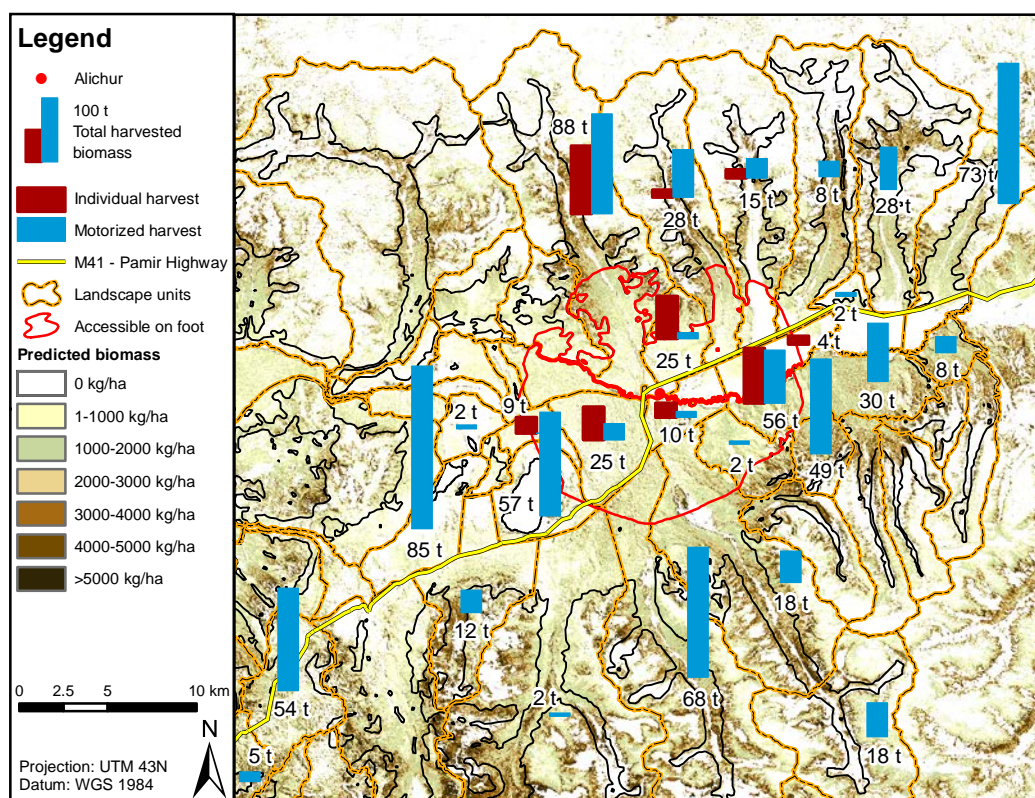
Fig. 4: Harvesting pattern and predicted biomass according to the empirical biomass model

In section 3.1.2 we derived *kuik* production figures of the animals kept in the Eastern Pamirs. Using the livestock numbers given in the household interviews, calculation of each household's *kuik*-self-supply rate is possible. *Livestock ownership* is therefore an essential category regarding a household's energy situation.

Harvesting dwarf shrubs is a labor-intensive activity. With up to 93 % of the dwarf shrubs' biomass located below the ground (Yusufbekov and Kasach 1972), the act of digging out the dwarf shrubs and carrying dwarf shrub bundles (*teng*) entails substantial physical labor. Therefore, *workforce* is a crucial category for biomass acquisition. Hoeck et al. (2007) state that in the Western Pamirs, harvesting biomass is mostly performed by women and children. However, our findings suggest that mainly men between the ages of 15 to 45 are employed in this activity. We found that at least one man in this age group is needed to collect enough dwarf shrubs to satisfy 50 % of a household's average annual energy consumption. If a household's total annual energy consumption should be satisfied by dwarf shrubs, at least two men at the specified age are needed. This positive influence to energy security due to increased

participation of household members in energy resource supply is different to the concept presented in Mirza and Szirmai (2010), where increased involvement of household members contributes to energy poverty. Again, this shows that energy poverty indices have to be adapted to the regional objective.

Households possessing at least one of the three factors of *monetary income*, *livestock ownership* or *workforce* in *sufficient quantity* and one factor in *medium quantity,* or who possess all three factors in *medium quantity* are considered energy secure (Tab. 3). These households dispose of enough resources to supply themselves with energy carriers to satisfy no less than 150 % of their current energy demand. Through diversification in these households' energy consumption, energy secure households are not vulnerable and can resist smaller shocks to the energy system. Households with only one factor at a *sufficient quantity* and all other factors at *low quantities* or with only two factors at a *medium quantity* are classified as *endangered by energy poverty*. Even though these households can currently satisfy 100 % of their entire energy demand and potentially even more, they are vulnerable to shocks. A shortage in one of the factors, caused for instance by a sick household member, unemployment or high

losses of livestock during winter, cannot be compensated. Finally, households, which can currently only satisfy less than 100% of their energy demand by themselves and are relying on external help, are classified as *energy poor*.

Ninety four of the household interviews contained complete and consistent information on the described factors. The situation of 56 of these households (60%) was classified as *energy secure*. While 24 households (25%) can currently supply themselves with energy but are *endangered by energy poverty*, 14 households (15%) are *energy poor* at present, according to this classification. With an annual demand of 205 t of dwarf shrubs harvested by individual harvest and 502 t harvested by motorized harvest and 8,343 t to 10,080 t of dwarf shrubs accessible for *individual harvest*, resp. 63,821 t to 75,479 t accessible for *motorized harvest*, the current harvesting practices can be continued for a considerable period of time even without considering regrowth. We therefore conclude that biomass availability is sufficient in the medium-term and dwarf shrub supply will not cease within the near future. However, the spatial distribution of biomass and related harvesting patterns show that the largest quantities are located in areas at considerable distance to the vil-

lage center or in regions that are difficult to access (e.g. valley slopes). The present harvesting situation suggests that considerable resources are needed to harvest dwarf shrubs even today. However, considering that the regrowth rates of dwarf shrubs are potentially below the current rate of usage, future access to dwarf shrubs may be even more costly in terms of workforce needed (and capital when *motorized harvest* is considered). According to our method of estimating energy poverty, increasing the workforce needed to gather dwarf shrubs negatively affects the local household's energy security situation. For instance, if the workforce required to supply a household with sufficient dwarf shrub biomass would double in the future, only 27 households (29%) could consider themselves energy secure, while 35 households (37%) would be endangered by energy poverty and 32 households (34%) could not supply themselves with the energy they require (Fig. 5).

Our results demonstrate that energy poverty is a complex phenomenon, which depends on a number of regionally varying social, economic and natural factors. This finding is similar to the results of SRIVASTAVA et al. (2012), who revealed that energy poverty strongly varies according to local con-

Tab. 3: Categorization of the local energy situation

	Sufficient quantity	Medium quantity	Low quantity
Monetary income	At least 100% of the average annual energy consumption can be purchased by the annual monetary income	At least 50% of the average annual energy consumption can be purchased by the annual monetary income	Less than 50% of the average annual energy consumption can be purchased by the annual monetary income
	36% of the annual income >= 504 USD	36% of the annual income >= 252 USD	36% of the annual income < 252 USD
Livestock ownership	The livestock owned produces enough *kuik* to cover at least 100% of the average annual energy consumption	The livestock owned produces enough *kuik* to cover at least 50% of the average annual energy consumption	The livestock owned produces less *kuik* than required to cover at least 50% of the average annual energy consumption
	kuik production >= 12.3 t	*kuik* production >= 6.2 t	*Kuik* production < 6.2 t
Workforce	The household's workforce can harvest enough dwarf shrubs to cover at least 100% of the average annual energy consumption	The household's workforce can harvest enough dwarf shrubs to cover at least 50% of the average annual energy consumption	The household's workforce cannot harvest enough dwarf shrubs to cover at least 50% of the average annual energy consumption
	Workforce>=2 persons	Workforce=1 person	No workforce

ditions. As Pereira et al. (2010) point out, analysis of energy poverty always depends on the definition of a poverty line, which in turn depends on a profound understanding of the utilization of energy resources. Our in-depth analysis of Alichur's local energy system suggests that, in the Eastern Pamirs of Tajikistan, besides monetary income and livestock ownership, the ability of a household to access local energetic resources is the main factor determining regional energy poverty. Other factors, which are only partly addressed by our energy poverty index, are the social structure of households and social networks within the community, which might also affect a household's energy supply, demand and coping strategies in bottleneck situations, but are difficult to quantify (e.g. Johnson and Brydon 2012; San et al. 2012; Mislimshoeva et al. 2014). Finally, regional disparities are significant within the Eastern Pamirs of Tajikistan and different energy carriers may be decisive for the regional energy situation in other villages, as examples given in Kraudzun (2014) show.

5   Conclusion

This study is the first interdisciplinary analysis of an energy system located in the Eastern Pamirs based on extensive quantitative and qualitative surveys. The study shows that existing energy poverty indices are not adequately capable of distinguishing between different energetic circumstances of households in the Eastern Pamirs. The energy system analysis performed in this study demonstrates that *monetary income*, *livestock ownership* and *workforce* of households are fundamental to ensure energy supply in this peripheral mountain setting and are important indicators for regional energy poverty. The derived energy poverty index for Alichur includes

these aspects and results in a highly diversified energy situation of local households. This confirms Barnes et al. (2011) and Srivastava et al. (2012), who state that energy poverty indices have to be adapted on a regional scale. Furthermore, as energy access and therefore energy poverty is determined by a number of factors, our results emphasize the complexity of this field and the importance of interdisciplinary research strategies. Finally, we showed that a profound characterization of the local energy situation in peripheral mountain regions is only possible with a combination of social and environmental data.

We suggest that presently only a small share of Alichur's population is affected by severe energy poverty. According to our index, the majority of the local households may be considered energy secure or at least able to satisfy their current energy demand without external help. These new, empirically-based findings confirm our initial hypothesis and contradict earlier studies that depict a widespread and severe energy crisis in the Eastern Pamirs. However, our results also support the second hypothesis stating that the energetic dependency on regionally available dwarf shrubs in combination with increasingly difficult accessibility may significantly reduce energy security in the future. As energy poverty is not only based on regional resource availability but also depends on demography, future access to markets (e.g. China) and the price of coal, a comprehensive outlook on future developments is beyond the scope of this study and requires additional data, models and research. Further studies, focusing on livelihood strategies, local particularities of energy poverty and dwarf shrub regeneration could improve the picture of dynamic ecological aspects, as well as of social and economic features of households influencing consumption patterns and therefore, energy poverty at the micro-level.
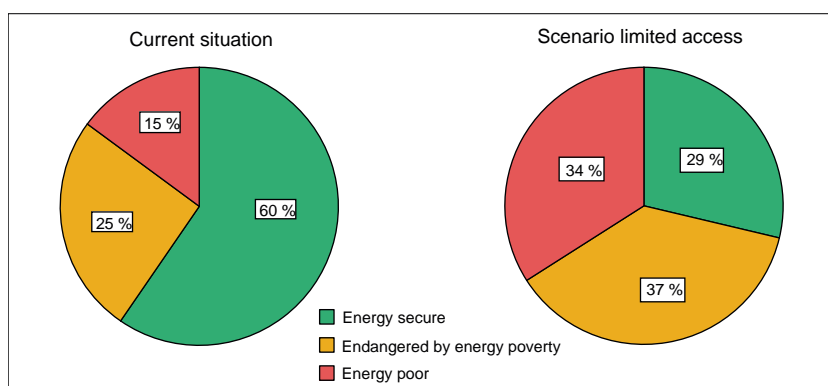

Fig. 5: Energy poverty in Alichur: a) Current situation and b) Situation with limited access to dwarf shrubs

Acknowledgements

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Authors

Georg Hohberg
University of Stuttgart
Department of Landscape Planning and Ecology
Kepplerstr. 11
70174 Stuttgart
Germany
e-mail: georg.hohberg@ilpoe.uni-stuttgart.de

Fanny Kreczi
Freie Universität Berlin
Institute of Geographical Sciences
Centre for Development Studies (ZELF)
Malteserstr. 74-100
12249 Berlin
Germany
e-mail: f.kreczi@fu-berlin.de

Harald Zandler
University of Bayreuth
Department of Geography
Nuernbergerstr. 38
95440 Bayreuth
Germany
Email: Harald.Zandler@uni-bayreuth.de