Kafue Gorge Lower: A low-impact addition to an existing hydropower cascade in Zambia

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Kafue Gorge Lower HPP is presently under construction, added to a cascade of two already existing dams on the lower Kafue River in Zambia. First, Kafue Gorge Upper (KGU) HPP was implemented at the inlet of the Kafue Gorge in 1971, followed by the construction of a dam and a reservoir further upstream, at Itezhi-Tezhi (ITT), in 1978; this latter structure has the main purpose of creating a large reservoir with overannual storage for regulating the flow to KGU, which itself only has a small reservoir with very limited storage. In this way, flow to KGU could be regulated to make it independent from the natural seasonal fluctuations in river discharge, which severely limited electricity generation in the low flow season. In order to optimize the use of the water resource, it was then decided to add KGL a short stretch downstream of the existing KGU dam and power house. KGL HPP consists of a 750 MW hydropower station with a 140 m high RCC dam. The expected volume of the reservoir at Full Supply Level (FSL) of 579 m above sea level is 83 hm³, covering an area of 1.85 km² and submerging the Kafue River up to the KGU tailrace outlet. It is located in southern Zambia on the Kafue River, a primary tributary of the Zambezi River, 55 km west of the confluence of these two rivers and about 60 km south of the capital Lusaka. ZESCO, the project proponent, prepared the initial ESIA study using its in-house expertise. This was subsequently updated and brought up to international standards by Pöyry Switzerland. The ESIA clearly demonstrated that this project can be qualified as a low-impact project, mainly for the following reasons: (i) It is the lowermost of three dams on the Kafue River, which flows into the Zambesi River in the stretch between Kariba and Cahora Bassa dams; for these reasons, it does not constitute an additional or new threat to fish migrations, and the incremental effect on changing river characteristics is very small. (ii) The reservoir covers an area of only 1.85 km², submerging a very small land area. (iii) The affected land is in a rather natural situation with low human influence, however, covered by a type of very widespread vegetation without specific biodiversity conservation value. (iv) Since it is located in a gorge, there was no room for agriculture and therefore there were no human settlements; in total, only 25 families of fishermen living along the affected part of the river had to be relocated. During the planning process, it was finally decided to operate KGL as a peaking plant. This will have an impact in the downstream area by causing short-term fluctuations in river discharge. From the point where the Kafue River leaves the gorge to its confluence with the Zambesi, on a stretch of about 30 km, the river banks are used for seasonal cultivation. This activity will be affected, and at least some parts of these river banks will no longer be available for cultivation. This impact and the required compensation are presently under detailed investigation.

1. The Project

1.1 Location and context

The Project, Kafue Gorge Lower HPP (KGL), is located in the lowermost part of Kafue River, a short stretch upstream of its confluence with Zambezi River. The following Figure provides an overall view of the situation.

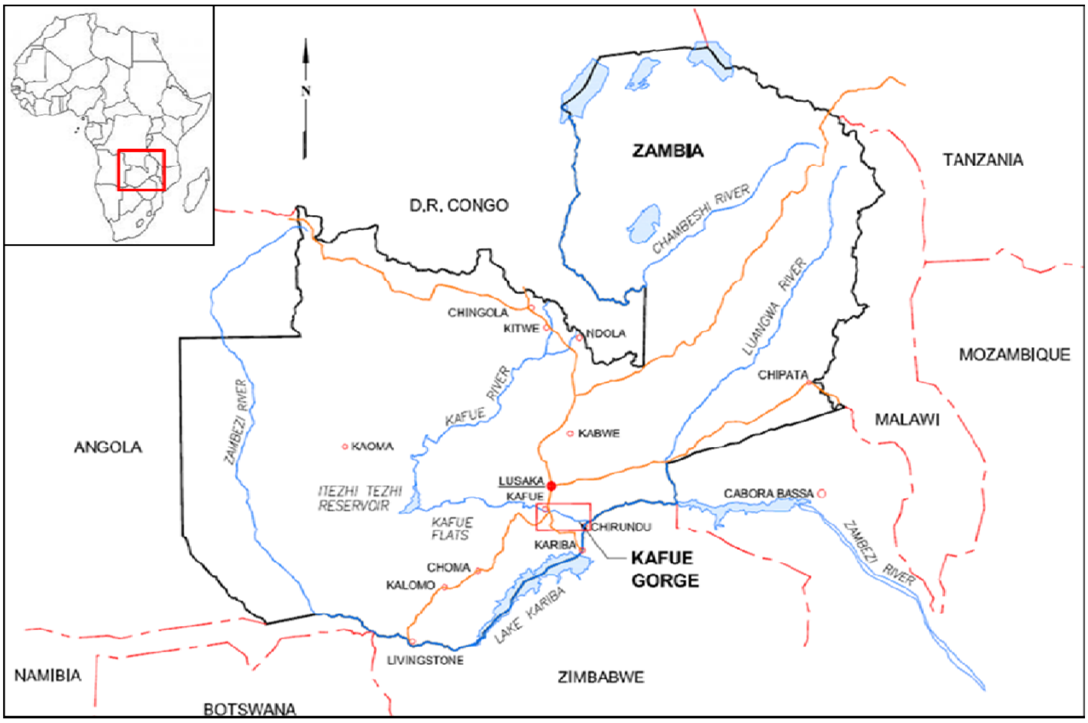

Fig. 1. Map of Zambia with Kafue Gorge highlighted
Source: MWH 2010

1.2 The Kafue Cascade

The Kafue cascade as such consist in three dams and power plants, namely (from up- to downstream) the two existing dams Itezhi-Tezhi (ITT) and Kafue Gorge Upper (KGU) and finally Kafue Gorge Lower (KGL), presently under construction. However, in order to understand the situation it is necessary to take two other dams into consideration as well, namely Kariba and Cahora Bassa, the two major dams and reservoirs on the Zambezi River. This entire system is shown in the following Figure; note that in this Figure KGU and KGL are indicated only as dam location, both of these reservoirs are too small as to be shown at this scale.

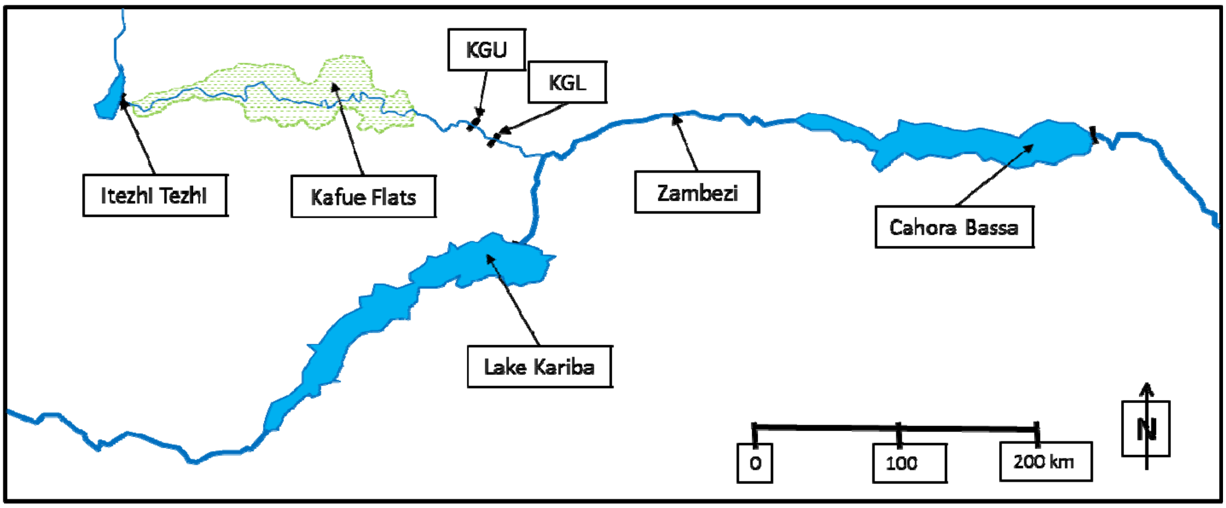

Fig. 2. The Kafue cascade and the relevant dams on the Zambezi

KGU was the first dam built on Kafue River. Like many dams on strongly seasonal rivers, it faced the problem of low flows in the dry season, insufficient for generating energy at full capacity, while in the wet season a considerable amount of water had to be evacuated over the spillway. In order to improve this situation, Itezhi-Tezhi dam was built, which originally had the only task of regulating flows for KGU; only recently, a power plant was integrated in this dam which allows to turbine the water that it passed through the dam. Figure 2 also shows the Kafue Flats, a large and ecologically important wetland (river floodplain); the regulation of the flow, reducing wet season high flows and increasing dry season low flows had considerable negative impacts on this important wetland (see below). The main features of the five dams in the system and shown in Figure 2 are summarised in the following Table.

Table 1: Major reservoirs on the Kafue and Zambezi rivers

Name	Abbr.	River	Storage capacity [hm³]	Water surface [km²]	Start year	Dam height [m]	Inst. capacity [MW]
Itezhi Tezhi	ITT	Kafue	7'000	375	1978	62	120
Kafue Gorge Upper	KGU	Kafue	950	13	1971	50	900
Kafue Gorge Lower	KGL	Kafue	83	1.85	uc (2017)	140	750
Kariba	/	Zambezi	200'000	5'500	1959	128	1626
Cahora Bassa	/	Zambezi	85'000	2'700	1975	171	2075

1.3 Kafue Gorge Lower

KGL dam is situated downstream of KGU, both of them being located within the Kafue Gorge, a steep and narrow section of the Kafue River which drains the Kafue Flats towards the Zambezi. The following Figure shows the two reservoirs and the layout of waterways and power houses. The main features of KGL are summarised in Table 2.

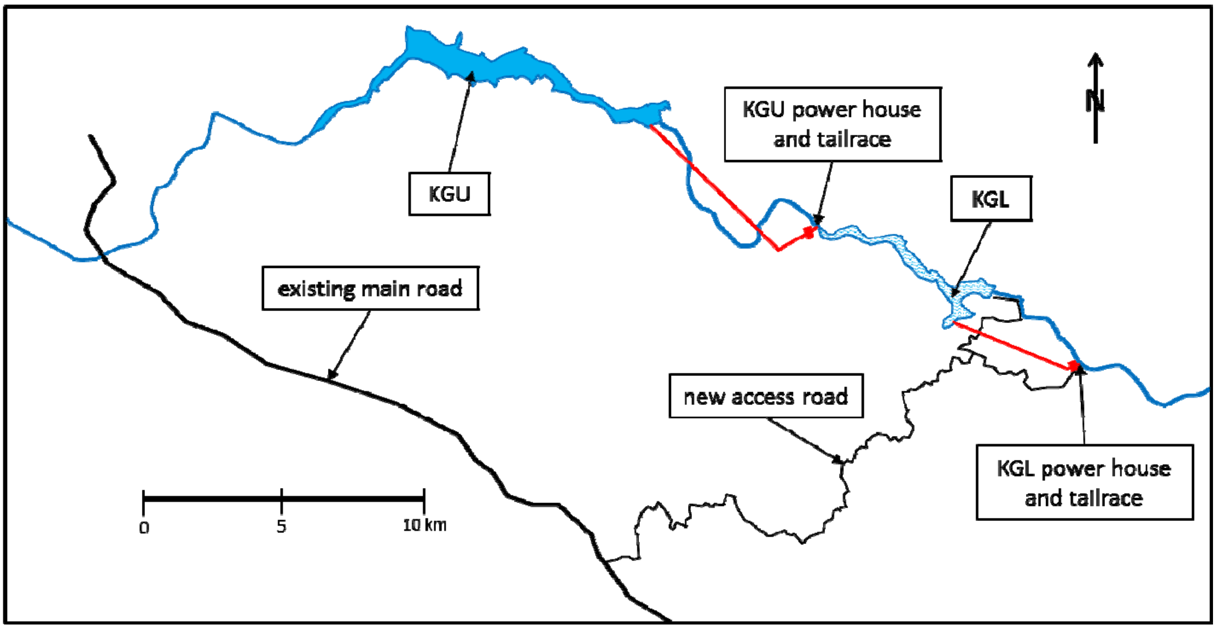

Fig. 3. Layout of the two HPPs in the Kafue Gorge

Table 2: Key characteristics of Kafue Gorge Lower HPP

Parameter	Unit	Value
1. Dam		
Dam type		RCC
Height	m	140
Crest length	m	376
Crest elevation	m asl	581
Riverbed elevation	m asl	441.0
2. Reservoir		
Full supply level (FSL)	m asl	579.0
Minimum operation level (MOL)	m asl	530.0
Area at FSL	km²	1.85
Area at MOL	km²	0.76
Volume at FSL	hm³	83.0
Volume at MOL	hm³	21.8
Active storage	hm³	61.2
3. Capacity		
Total installed capacity	MW	5 x 150 = 750
Rated hydraulic head (net-head)	m	173.3
Turbine output	m³/s	5 x 96.8 = 484
4. Hydrology		
Catchment area	km²	153'570
Mean annual rainfall	mm	1010
Average discharge at dam site (1961-1990)	m³/s	315
Average discharge at dam site (1973-2012)	m³/s	276
Flood (HQ_{1000})	m³/s	3'770
Flood (PMF)	m³/s	7'228
5. Permanent access roads		
Construction (new road)	km	22
Track upgrade	km	24

2. Impacts

A number of impacts can be characterised as usual or "normal" impacts of dam projects (Zwahlen 2003:302). While these impacts arise in basically every dam project, their importance and magnitude can obviously vary to a very great degree, depending on the specific characteristics of the project and the conditions of the project area.

The following paragraphs shortly discuss these main impacts by first stating the general type of impact and then presenting the case of KGL for this particular issue. A detailed assessment of impacts can be found in the ESIA Report for this project (Pöyry and Zenith 2016).

2.1 Interruption of a river continuum

The fact that a dam is built across a river will always interrupt a system that was, up to that point in time, an entity. Direct consequences of this interruption are a change in sediment transport (mainly due to sediment retention in the reservoir), an interruption of fish migration (complete for upstream migration, obstacle and risk for downstream migration), and an obstacle for or interruption of drift (i.e., the more or less passive movement of various organisms downriver). This interruption of the river is arguably the most severe impact from an ecological point of view, since it invariably induces changes in the rive ecosystem up-and downstream of the dam, and since it also leads directly or indirectly to the other impacts mentioned below. There is a vast literature describing this impact, mainly concerning fish migration; suffice to cite just one well-known example: the complete disappearance of the Atlantic salmon (*Salmo salar*) from much of its former range in the River Rhine basin in Europe, an extinction caused by the cascade of dams on this river (Pedroli et al., 1991: 40).

The case of KGL: as any high dam, KGL dam interrupts the river on which it is built. However, the following points need to be considered:

- Kafue River is already interrupted by 2 dams (KGU and ITT), KGL dam site being at a mere 17 km downstream of the existing KGU dam.
- The main river, the Zambezi, is also interrupted by 2 dams, Kariba and Cahora Bassa.
- In his study of fish of Lake Kariba, Balon (1974) does not mention any migrating species that might have had their migrations interrupted by Kariba dam; in any case, such migrations would have ended, in the best of cases, at the Victoria Falls, which are a natural barrier for any fish migration. There were other falls, which have disappeared when Kariba and Cahora Bassa dams were built, which might have stopped fish migrations as well.

It can be said that the middle Zambezi is a kind of a closed system where fish migrations are concerned, the two large dams being the boundaries of this system, which in addition to that was closed even more by KGU dam; KGL changes this situation only marginally.

2.2 Change in river discharge pattern downstream of the dam

This effect is closely related to the first one. In this respect, two main parts of the river can be identified: (1) between the dam and powerhouse outlet, where discharge is reduced, in extreme cases to zero, and (2) downstream from the power house outlet, where river discharge is influenced by plant operation. The magnitude of the second of these effects depends mainly on two conditions, namely (i) the size of the reservoir and (ii) the operating pattern of the power plant. Small reservoirs are often operated as run-of-river (ROR) power plants, which have no or very little impact on the river discharge pattern in the downstream area. At the other end of the range are very large reservoirs with annual or even over-annual storage which can influence the seasonal flow distribution in the river, usually by storing water and thus lowering the discharge in the high flow season and releasing this water and thus increasing discharge in the low flow season; this is often the main purpose of such reservoirs, as was e.g. the case for the Itezhi-Tezhi dam on the Kafue River (see Figure 4).

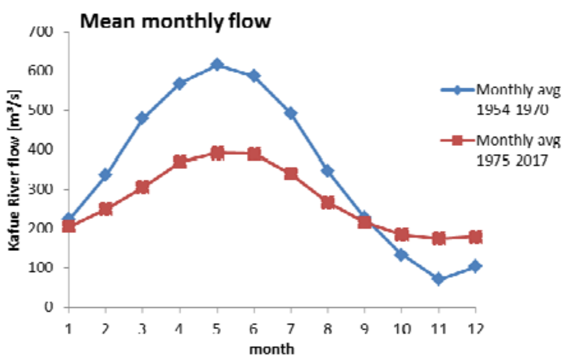

Fig. 4. Mean monthly flow at KGU before and after construction of ITT

The case of KGL: originally, KGL was planned as a ROR scheme, just turbining the inflow from KGU. In that case, KGL would not have any additional impact on downstream flows, the present situation would have been maintained. A considerable change in the system had been brought about by the Itezhi-Tezhi dam, which was built for regulating the flow of Kafue river with the main aim of making more water available for KGU in the dry (low flow) season. This change had a considerable impact on the Kafue Flats, the large floodplain between Itezhi-Tezhi and the upper end of Kafue gorge (Godet and Pfister, 2007; WWF, 2003) by reducing the difference between high and low flow, an important ecological driver in such floodplains. KGL will benefit from this correction in seasonal discharge, but it will not change in any way, thus causing no additional impact.

It was then decided to change the design of KGL in order to operate it as a power plant with daily peaking. This means that the reservoir will be drawn down by up to 49 m (FSL being at 579, MOL at 530 m asl) during daily peak demand hours, and filled again during low demand hours. This operation pattern will have a significant effect on the downstream situation. Work for assessing this impact is currently under way, but it is already possible to roughly say what the probable outcome will be:

- In the uppermost part, the Kafue Gorge below the power house, there will be a surge wave each time the turbines are started, which will then gradually flat out with increasing distance from the tailrace outlet; since the river flows there in a narrow and rather steep gorge, this will have a limited negative impact, but it will present a danger for anybody who would be in proximity of this part of the river.
- In the middle part, below the gorge, where the river enters the Zambezi floodplain, the effects will be less marked. Still, daily fluctuations of a magnitude which could closely resemble the difference between natural (present) fluctuations in the dry and the low flow season can still be expected there. This can represent a risk for users of the river, and it might prevent the continuing use of some of the river bank gardens which are now being cultivated during the low flow season (Figure 5 left). Since this part of the river and the surrounding land are used quite extensively, this is the impact to be investigated.
- Finally, the lowermost part of the Kafue river is directly influenced by the Zambezi, and as such by the operation of the Kariba HPPs, which can cause a backwater effect into the Kafue; this, obviously, is not an impact of KGL, but the limit between these two river zones still needs to be identified.

2.3 Change from river to lake conditions

This type of change will happen in the part of the former river where after impoundment there will be a reservoir. Water quality will change due to this effect, and the new lake is a habitat very different from that of the former river. Here again, extent of change as well as similarity of the reservoir with a natural lake will depend very much on the specific conditions, size of the reservoir and operation pattern being the most important parameters. Some reservoirs have developed into valuable habitats, like e.g. the Klingnauer Reservoir in Switzerland, a small, shallow reservoir which has developed into an wintering habitat of international importance for water birds (Marti and Schifferli, 1987). The Itezhi-Tezhi reservoir as well is a suitable habitat for a number of species and a tourist attraction (Ashley, n.d.; Figure 5 centre). Other reservoirs however, and especially narrow and deep reservoirs with steep slopes and a considerable seasonal drawdown, have very little value as habitat.

The case of KGL: As mentioned, the KGL reservoir will have the following main characteristics: small area (1.8 km²), small volume (83 hm³), deep (maximum depth just upstream of the dam approximately 138 m), steep shores since it is located in a gorge-like narrow valley, water turnover rate of about 3.5 days and with a daily drawdown of almost 50 m. All this means that the KGL reservoir will have little resemblance with a natural lake, and that it will not be a suitable habitat for any species of aquatic plants and animals. The advantage of the rather small volume and the high turnover rate is that its water quality will remain good (no deterioration due to submerged biomass, since the amount of biomass will be small, and any nutrients will very quickly be flushed out. The shore areas, i.e. the fringe of the lake up to a depth of about 10 m, which are usually the most productive areas of a lake, will be exposed to daily changes between dry and submerged, and will consist in bare rock, no suitable habitat for any organisms. This means that the potentially beneficial development of a lake shore habitat will not materialise in this case.

Fig. 5. Kafue river bank gardens (left); Itezhi-Tezhi reservoir (centre); topography and vegetation in the Kafue Gorge (right)

2.4 Destruction of terrestrial habitats

All terrestrial habitats within the reservoir area are permanently destroyed during reservoir impoundment. Terrestrial vegetation and fauna of these habitats will disappear during impoundment. Importance of this effect depends directly on reservoir size and on the type of habitat or habitats that will be submerged.

The case of KGL: upon impounding of the KGL reservoir, about 1.6 km² of terrestrial habitat will be submerged (the remaining 0.2 km² corresponding to the present river). The terrestrial habitat present there is mostly Miombo woodland (with *Brachystegia sp.* as the most important tree) on steep slopes (Figure 5 right). It is rather intact, showing little if any man-made change. In this sense, it can be considered as a rather pristine area. However, this is a type of vegetation which is very widespread in Zambia; in addition to that, there is no indication that the affected area would be an important habitat for any species of wildlife, or for any rare, endangered or endemic species of plants and animals, and for this reason it does certainly not qualify as critical habitat as defined in IFC's Safeguards (IFC 2006: PF 6:25). The area submerged is very small in relation to the total habitat of the same type in the wider area of the project. Therefore, this can be considered as a permanent, but insignificant impact.

2.5 New access roads

In cases where a new access road needs to be built for the construction of a dam, this can have major consequences. Although the direct impact of the roads, in terms of area occupied, might be rather small, the roads can trigger a development not directly related to the project as such, especially in cases when hitherto inaccessible areas are made accessible in this way; this can have very considerable, long term environmental effects.

The case of KGL: for the project, a new all-year and all-weather access road of approximately 22 km had to be built. Before that, there was already a track along the river from KGU to the KGL dam site, which however was often interrupted by creeks and small landslides during the rainy season and which therefore was not manageable by vehicles for most of the time.

The new access road now provides permanent access to the site in a way that was not possible before. This can cause indirect, not project related impacts on the area along the road. As a matter of fact, a recent site visit showed that already some people are moving in along the road for producing charcoal, and there is a risk that people could move in to establish themselves in the project area; this, especially if people would install themselves in the vicinity of the river downstream of the tailrace, would expose them to the risk of the surge wave. This means that surveillance of the area is required for preventing this type of development to happen. Otherwise, the risk of adverse impacts due to the access road is small, since the ecosystems made accessible cannot be considered as fragile or especially vulnerable.

Notably, presumably also due to the rather remote location of the construction site and the fact that no hiring of labour takes place on site, after 2 years of ongoing construction activities there are still no camp followers having installed themselves in the vicinity of the construction site, a development that is known to cause considerable problems in many such projects.

2.6 Social Impacts

These can be manifold. The most important in many cases is the involuntary resettlement as a consequence of a dam project, which can be very considerable, and which is never an easy task to manage and to mitigate. In addition, there are also other negative socioeconomic impacts, such as effects on the population in the downstream area (through disruption of river floodplain dynamics, groundwater table changes, etc.); immigration into the area, especially during the construction phase, as a consequence of job opportunities; and effects on the host population for the resettlers. An HPP can also have positive effects on the local community, like providing jobs and therefore income (although often limited to the construction phase), improved access through better roads, improved infrastructure, rural electrification etc. These positive items have to be evaluated, planned and implemented carefully in order to have the expected effect. Finally, the generation of electricity as a reliable and affordable form of energy will have a positive effect on the economy and the life of people, and this on a regional, national or even international level.

The case of KGL: one usual and very common conflict between dam projects and the local population arises from the fact that very often fertile alluvial soils can be found along the rivers, which are very suitable for agriculture and therefore usually sustain a large human population. In such a situation, the construction of a dam and the creation of a reservoir will submerge such land, making the relocation of the local population unavoidable. This was not the case in this project. Since the river here flows through a rather narrow, steep gorge, the river bed and its banks consist in bare boulders and rocks, and on the mountain flanks along the river there is no suitable land for agriculture. Given this situation, and the difficult access to the area, there were only 25 households living in the area of the future reservoir, which lived entirely from fishing in the river. These 25 HH had to be relocated. About half of them chose to be relocated to the village to which they administratively belonged (even if this village was located away from the river in a distance of about 30 km), while the other half chose the possibility of receiving cash compensation and self-resettlement. This is a very small number of people to be relocated for a project of that size.

2. Conclusions

KGL can be considered as a good example of a low-impact hydropower project (meaning: a project without any major negative environmental and social impacts). This has two main reasons, which are largely independent from each other:

- The nature of the site as such, which does neither contain any habitats that are of importance for biodiversity conservation nor an important human population; this means that negative impacts on the biological aspects of the environment as well as on the local socio-economic conditions were minimal.
- The fact that it is located within a cascade of already existing dams; the direct consequence of this is that impacts on the river and aquatic habitats within it are minimal, while at the same time the use of the water as a resource for energy generation is optimised.

This does not mean that every dam, reservoir and power plant added to an existing cascade can automatically be considered as a low impact scheme; it will still be necessary to carefully evaluate each case. Even so, using a river in this way may be one way for minimising environmental and social impacts of hydropower.

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