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Inter- and Transdisciplinary Collaboration in an International Research Project – The Case of the German-Ghanaian Project EnerSHelF (Energy-Self-Sufficiency for Health Facilities in Ghana)

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Abstract

Interdisciplinary research (IDR) is a widely applied research approach, combing the efforts of multiple academic disciplines to work on complex problems. Within transdisciplinary research (TDR), non-academic stakeholders participate in the project and offer hands-on experience to the research. These integrative approaches are praised for the ability for addressing 'wicked problems' and can lead to new perspectives on relevant contemporary challenges. This working paper is analysing the cooperation and exchange of involved disciplines in the German-Ghanaian interdisciplinary research project Energy-Self-Sufficiency for Health Facilities in Ghana (EnerSHelF). The results are presented in a Collaboration Frequency Network (CFN) as well as qualitatively examined to unravel the level of interaction and perspectives on chances and challenges of IDR and TDR. The analysis shows that disciplinary closeness, data collection and exchange, and individual effort are affecting the level of collaboration among other reasons. Concluding the authors develop recommendations for future IDR and TDR projects.

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List of Abbreviations

BMBF	German Federal Ministry of Education and Research
CFN	Collaboration Frequency Network
EnerSHelF	Energy-Self-Sufficiency for Health Facilities in Ghana
ID	Interdisciplinary
IDR	Interdisciplinary Research
MDR	Multidisciplinary Research
PI	Principal Investigators
PSN	Participation Strength Network
PV	Photovoltaic
TD	Transdisciplinary
TDR	Transdisciplinary Research
WP	Work Package

1. Introduction

The accelerating impact of humankind on the environment has led to the 21st century being referred to as the age of the Anthropocene (Pipere & Lorenzi, 2021). Prominently put on the agenda by Paul Crutzen and Eugene Stoermer in 2000, Anthropocene describes a new geological epoch of the earth, where humanity became a powerful geological force and the core-agent in the world's system, influencing its environment and global climate significantly (Crutzen, 2002; Trischler, 2016). Today, we are confronted by various challenges such as a growing global population, increased urbanization, intensified land utilization, food insecurity, increasing energy demand, and the pollution of land, water, and atmosphere – to name a few. These challenges not only demand new ways of managing the world, but also require academia to restructure science to adequately face these complex problems. To understand global change and multi-layered human-environment interaction, scientific projects need to aim for transformation-oriented research, with more than one discipline to search for solutions (Uiterkamp & Vlek, 2007; Halvorsen et al., 2016; Tobi & Kampen, 2018; Gertschen, 2021; Pipere & Lorenzi, 2021). This type of collaboration can have different forms, often divided into multi- (MDR), trans- (TDR) or interdisciplinary research (IDR) (Klein, 2008; Barthel & Seidl, 2017). While MDR is an additive approach that combines efforts of different disciplines speaking in separate academic voices, the latter two represent a form of integrated science by bridging disciplines and differ mainly in their organisational structure and degree of collaboration with TDR characterized by research-practice collaborations and IDR by collaboration of different academic disciplines (Sahamie et al., 2013; Allen et al., 2014).

This paper adds to the current literature on integrative science by presenting a case study of the interdisciplinary (ID) German-Ghanaian research project Energy-Self-Sufficiency for Health Facilities in Ghana (EnerSHelF). The objective of the paper is to unravel the level of interaction of the involved academic disciplines and industry partner by applying a collaboration frequency network. Thereby, it offers a unique perspective into the characteristic and complexity of an international research project linking different disciplinary fields and stakeholders. Furthermore, it complements the current state of research by adding insights into challenges and barriers in IDR and TDR projects while offering suggestions on how to counterbalance these. Additionally, the paper allows for a unique perspective on the role of the accelerated digitalization of the project due to the Covid-19 pandemic and its effect on the level of collaboration within an international research team.

The paper is structured along two lines: Section 2 summarizes the literature on IDR to introduce strengths and challenges of IDR, while simultaneously feeding in aspects surrounding TDR as well.

Then, the empirical methodology is described in section 3. Section 4 presents the results of the empirical analysis. Section 5 presents the discussion of results, section 6 concludes.

2. Strengths and Challenges of IDR and TDR

IDR and TDR have become major themes in academic research and have increasingly been praised for their ability for complex problem solving or addressing "wicked problems" (Pérez Vázquez & Ruiz Rosado, 2005; Klein, 2008; Huutoniemi et al., 2010; Klein, 2014; McLeish & Strang, 2016; Pedersen, 2016; Arnold et al., 2021). The composition of IDR or TDR consortiums with different actors and disciplines is seen to foster transformation-oriented research (Gertschen, 2021). The strength of this collaborative research initiatives is that ID or TD engagement can lead to new ways of looking at problems with solutions not considered before by the other disciplines (Allen et al., 2014; Hans, 2015).

As an integrative approach, IDR is combining partners from different disciplines working together within a research project from problem definition to methodology (Barthel & Seidl, 2017). It entails a close collaboration of different scientific disciplines and the integration of theories, methods, concepts, findings, models, and data (Uiterkamp & Vlek, 2007; Allen et al., 2014). Thereby, it actively confronts but also bridges the prevailing disciplinary approaches (Huutoniemi et al., 2010). The level of cooperation can vary significantly. Within IDR, it is distinguished between "radical" and "moderate" (Holm et al., 2013) as well as "broad" and "narrow" (Huutoniemi et al., 2010). IDR is termed "radical" or "broad" when non-related scientific fields, like social sciences and natural sciences, are collaborating across disciplinary frontiers. "Moderate" or "narrow", however, means the collaboration of disciplines that are closer related, such as biology and chemistry.

Like IDR, TDR is an integrative approach and is described as the cooperation between academia and practitioners or other stakeholder groups (Allen et al., 2014; Barthel & Seidl, 2017), creating synergies through a combination of scientific knowledge and real-world experiences (Sahamie et al., 2013). In this process, stakeholders and researchers are described to be involved in a co-production of knowledge, addressing societal relevant problems (Schmidt & Pröpper, 2017). Ideally, it leads to mutual learning effects between science and society and formulates solutions to promote sustainable transition (Jahn et al., 2012).

While IDR and TDR as well as MDR have been a part of scientific research and discussion for decades (Huutoniemi et al., 2010), some argue that they have become buzzwords but not fulfilling the expectation in reality (Moran, 2010; Hans, 2015; Schmidt & Pröpper, 2017). To fully benefit from additive and integrated research approaches, Arnold et al. (2021) "seeks to advance discussions" on how IDR can be integrated and facilitated by faculties, university administration, research institutions, and department chairs. This paper adds to the discussion by offering lessons-learned from a practice-based case study.

Ideally in IDR and TDR projects, every discipline and stakeholder is bringing in their own strengths while weaknesses are compensated by the other project members (Szostak, 2013). For individual researchers, being involved in IDR or TDR can accelerate the understanding of other disciplines and open up new perspectives on real-world problems brought in by non-academic actors (Jahn et al., 2012; Pipere & Lorenzi, 2021). This way, IDR and TDR are more than the sum of its parts, but channel the different disciplines as well as stakeholders' and researchers' knowledge sources in the project's findings (McLeish & Strang, 2016). Consequently, it can promote spill-over effects by identifying new data that could be used by other disciplines within the research project (McLeish & Strang, 2016).

Besides the variety of positive effects and benefits integrative research approaches can have, IDR and TDR projects face specific obstacles and barriers additionally to the ones that occur in monodisciplinary projects. Many challenges are shared across projects while some are highlighted to be highly context-specific (Sievanen et al., 2012). Multiple guidelines have been developed on how to enhance and facilitate both IDR and TDR (Di Castri & Hadley, 1986; King et al., 2008; Oughton & Bracken, 2009; König et al., 2013; Beichler et al., 2014; Pohl et al., 2015; Pischke et al., 2017; Tobi & Kampen, 2018; Burgers et al., 2019; Cvitanovic et al., 2020). While some are adapting existing frameworks from academic fields such as organisation management or organisational psychology (König et al., 2013; Cvitanovic et al., 2020), others are developed based on previous experiences conducting ID research (King et al., 2008). Furthermore, some researchers are proposing steps for planning and conducting IDR without developing a new framework or calling it as such (Di Castri & Hadley, 1986). This can include proposed steps for a specific part of an IDR project, such as publication procedures (Pohl et al., 2015). Despite the growing number of these guidelines, Pedersen (2016) calls for more appropriate frameworks for IDR. This is also pointed at for the evaluation of IDR projects. Within IDR and TDR, the validation of the research outcomes can be influenced by stakeholders outside your own discipline or in the context of TDR outside academia itself (Podestá et al., 2013). For this purpose, it needs standalone frameworks for evaluation of IDR projects (McLeish & Strang, 2016). Such frameworks for evaluation are, for instance, presented by Klein (2008), Bark et al. (2016), Carr et al. (2018), Nastar et al. (2018) and Cvitanovic et al. (2020).

One of the main barriers to IDR as well as TDR is the limited time resource a project usually has. Due to higher communication efforts, longer integration in the beginning of the project, and the development of an understanding between the different disciplines requires more time than within monodisciplinary projects (Heberlein, 1988; Campbell, 2005; Institute of Medicine (U.S.), 2005; Klein, 2008; Halvorsen et al., 2016). However, a longer project period could also lead to researchers

leaving a project, which can have a discontinuing effect on collaboration across disciplines (Garwood & Poole, 2018).

Since disciplines often have their own 'dialect', communication with scientists from different fields as well as non-academic stakeholders can lead to misunderstandings caused by different working languages (Bracken & Oughton, 2006; Lang et al., 2012). Especially for broad IDR, communication gets more challenging with an increased cognitive distance between disciplines (Pedersen, 2016). However, if there is sufficient communication within the team – and this includes both regular communication as well as specifically about the topic (Holm et al., 2013) – it can strengthen the team and has the potential to generate new insights to the research problem itself (Institute of Medicine (U.S.), 2005).

An interconnected issue is the nonunderstanding of other disciplines and their thought styles (Pohl, 2011). Thought styles are built on the whole environment a scholar is based in. For instance, location, discipline, personal perspectives, and many more. Depending on how far apart the disciplines are, models and concepts might be too different to be easily understood by scientists from another field due to different epistemic goals and research strategies (Pedersen, 2016; MacLeod, 2018). Nevertheless, to facilitate IDR, even methods that seem incomparable could be compared to foster understanding between the disciplines (Tobi & Kampen, 2018).

For IDR and TDR to have a positive effect, it is required that all partners within a project value the work of other disciplines and are willing to understand their operating principles (Uiterkamp & Vlek, 2007; Tobi & Kampen, 2018). As Heberlein mentioned back in 1988, social sciences are sometimes grouped into "public relations" by natural scientists, while social scientists are misinformed about natural sciences, due to little exposure to one another. The dilemma, that social sciences and humanities are not taken seriously or are not even considered to be scientific at all, still exists, and is mostly due to the lack of knowledge of the other discipline (Holm et al., 2013; MacLeod, 2018). One way to counter this is to set a common goal or motive that ties the disciplines closer together (Uiterkamp & Vlek, 2007; Cvitanovic et al., 2020). Additionally a conceptual model helps to align the expectations about the project and its outcome (Bark et al., 2016). Specific training at the initiating phase of a research cooperation can have a positive effect on the understanding of each other's disciplines (Zinsstag et al., 2011; Halvorsen et al., 2016; Piso et al., 2016; Pischke et al., 2017). It also increases the likeliness that everyone knows how and on what their colleagues are working on (Haas & Hellmer, 2014). Thereby, principal investigators (PIs) as initiators of IDR or TDR projects should employ sufficient management skills to ensure its success and a common understanding of its goal and intention. Bark et al. (2016) suggest five management interventions:

First, agreeing on a conceptual model; second, incorporate an independent review process; third, support ways to informally translate research into accessible language for all; four, push for intra-project communication among team members; fifth, foster organisational learning to grant needed time and resources.

The organisational structure of research institutions as well as composition of funding schemes for research projects can hamper or complicate successful IDR or TDR. Universities have different departments in (mostly) different buildings – let alone the physical distance to involved stakeholders. Without having a shared workplace, researchers of an ID team are lacking a low-threshold way to maintain close contact with each other (Blättel-Mink et al., 2003). Also, the distribution of research funds for IDR have to somehow be split fairly between project partners (Heberlein, 1988; Institute of Medicine (U.S.), 2005). Even with funding agencies increasingly including IDR in their calls for proposals, the additional time needed as well as institutional flexibility are often not included (Halvorsen et al., 2016).

Another external impact are publications. While in earlier literature it was stated that it is hard to publish IDR at all (Heberlein, 1988), nowadays, the problem is on where to publish (Campbell, 2005). Disciplinary journals still have a better standing in many academic disciplines and a higher impact factor than IDR journals (Barthel & Seidl, 2017). Since publications are the key to a scientific career and reputation usually develops through publications in disciplinary journals with higher specialization, the rewards to work in IDR projects – especially early in the academic career – seem to be comparably low to monodisciplinary projects (Campbell, 2005; Fischer et al., 2011). This also holds true for the project itself. When it comes to evaluating research projects, the impact factor and citations from the publications are still commonly used, even though this practice is controversial (Klein, 2008; Bark et al., 2016).

International IDR or TDR projects bear additional challenges. While the physical distance is already a prominent issue for communication within the team, cultural differences need to be considered as well. This includes a process to integrate placed-based cultural views to foster discussions and understanding of project partners (Trebitz et al., 2021). This intercultural interaction is, to a large extent, influenced by structural conditions that should be addressed and considered (Müller, 1998). Again, addressing these issues should take place at the initial phase of a project. Trebitz et al. (2021) suggest a "culture-focused immersion course" as it is not enough to work together to overcome cultural differences and intercultural adequacy. IDR and TDR projects can also face false expectations when facilitating research in the Global South. At field sites, project partners might be mistaken as development workers with local residents expecting a practical outcome and benefit

of their work – leading to frustration if the goals are not communicated well. Additionally, there are regular power hierarchies at an institutional level between partners in the North-South context. For instance, African partners often have the status of sub-contractors of German partner institutions. This is seen as a barrier to establish communal trust within the team and hardens power relations and structural marginalisation (Schmidt & Pröpper, 2017).

3. Methodology

This paper is based on data collected throughout the project period of the international, IDR project EnerSHelF. The upcoming section is introducing the project before laying out the methods of data collection and analysis.

3.1 The case: Energy Self-Sufficiency for Health Facilities in Ghana (EnerSHelF)

The EnerSHelF project started in June 2019 and is scheduled to end in March 2023. It is funded by the German Federal Ministry of Education and Research (BMBF) through the Client II initiative. Within EnerSHelF, a team of nine partners consisting of academic researchers from social sciences and natural sciences as well as practitioners from both Germany and Ghana are involved – listed in Table 1. They work together on both technical and political-economy questions to improve and disseminate marketable Photovoltaic (PV)-based energy solutions for health facilities in Ghana. In total, six universities and research institutes, one extra-scientific institution, one network organisation, and one industry partner are associated with the project. The University of Applied Sciences Bonn-Rhein-Sieg is coordinating the project.

Table 1: Partners and Work Packages within EnerSHelF

Work Packages	Lead partner	Work area	Affiliated Partners
WP 1	H-BRS[1]	Political economy of a sustainable energy transition in the Ghanaian health sector (focus: PV)	SDD UBIDS[2]
WP 2	WestfalenWIND	Promoting user acceptance and sustainability	UDS[3], H-BRS
WP 3.0	H-BRS	Country- and sector specified optimization	-
WP 3.1	TH Köln/CIRE[4]	Electricity demand of the Ghanaian health sector	H-BRS, KNUST[5]
WP 3.2	UniA[6]	High resolution energy meteorological forecasts for Ghana	WASCAL[7]
WP 3.3	H-BRS	Tools for the country- and sector specific system planning and plant optimization	TH Köln/CIRE[4]
WP 3.4	RLI[8]	Development of an electrification strategy for medical institutions	-
WP 4	H-BRS	Requirements of a sustainable energy transition from an interdisciplinary perspective	-
WP 5	EADI[9]	Transfer and dissemination	-
WP 6	H-BRS	Management and coordination	-

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[5] Kwame Nkrumah University of Science and Technology
[6] University of Augsburg
[7] West African Science Service Centre on Climate Change and Adapted Land Use
[8] Reiner Lemoine Institut
[9] European Association of Development Research and Training Institutes

The practical part of EnerSHelF is supervised by a German renewable energy company, which set up a container system in Kologo, Ghana, with a PV-battery system that can be used as a standalone micro-grid or to support the grid, to ensure the uninterrupted electricity supply of a small health-facility. A Ghanaian industry partner filed for bankruptcy during the project period and was not replaced.

The thematic academic research is divided into two main work packages (WPs). One part includes economists and social scientists, who are looking at the political-economic perspective of PV in Ghana, to unveil what hinders or fosters the distribution of sustainable energy in Ghana. The other scientific part of the EnerSHelF project consists of engineers and climate scientists, who try to optimize the PV solutions in a way to be most suitable to the specific climatic conditions and demand-driven requirements. They are supported by WASCAL[1], which provides technical support in collecting, processing, and analysing observational data from the local observatory networks and pilot sites. News and updates of the project are regularly disseminated and communicated by EADI[2] throughout the funding period to stakeholders in the field of renewable energy and health.

An additional WP analyses the ID cooperation within the project and organizes monthly seminars, which are meant to facilitate the knowledge exchange between different work packages and to observe lessoned-learned for future IDR and TDR.

3.2 Methods of Data Collection

Two sources of knowledge were taken into consideration for the analysis: (1) Recurring semi-structured interviews with researchers and practitioners within the project, and (2) participatory observation by the authors of work-meetings within and across the six WPs as well as of monthly knowledge-transfer meetings. The method of data collection is in close proximity to the approach of Schmidt and Pröpper (2017) evaluating TDR in a similar research setting.

A set of four rounds of semi-structured interviews were conducted. Due to the Covid-19 pandemic and the geographical distance to some of the researchers, all interviews were held online. The first round of interviews (n=13) took place in November and December 2020 and was not recorded, but reminder logs were created right after the interviews. All other rounds were recorded. Within the interviews, the project partners were asked with whom they work and how regularly. Additionally,

[1] West African Science Service Centre on Climate Change and Adapted Land Use

[2] European Association of Development Research and Training Institutes

they shared their perception and experience of IDR and TDR and where cooperation is needed within EnerSHelF across WPs.

The second round of interviews took place in July and August 2021. However, the number of interviews only reached n=5, as the time proved unfitting for most researchers and the team underwent personnel transitions. The second round saw a repetition of questions from the first round measuring the cooperation across WPs, the researchers' perceptions of interdisciplinarity in the project, and where they see the need for an increased exchange. This was meant to measure continuities and possible changes of the degree of cooperation. Questions concerning the digitalization of work within EnerSHelF as well as the perception of a newly introduced monthly seminar were included.

The third round of interviews (n=10) was conducted in January and February 2022, covering all WPs. Except the aspect of digitalization, the scope of questions was in line with the second round of interviews. Despite two previous rounds of interviews, for the first time, the authors were able to interview two of the Ghanaian project partners.

The fourth round of interviews (n=15) took place in August and September 2022, including both researchers as well as PIs from Ghana and Germany. Besides asking about the continuity of exchange and cooperation of the different WPs during the past months, the interviewees were asked for a final perception and assessment of the interdisciplinarity within EnerSHelF and the project overall.

To understand and examine the collaboration within the EnerSHelF project, regular and irregular work meetings taking place online were observed. Since knowledge transfer is an advantage of IDR, monthly meetings were set up to foster such exchange. Notes of both types of meetings were included in the analysis of characteristics and factors influencing IDR or TDR, of the thematic content that initiatives both, and of the accelerated impact of digitalization.

3.3 Methods of Data Analysis

The collected data are analysed across four lines: (1) The collaboration frequency between different WPs and disciplines and their timely development. (2) The thematic breakdown of collaboration and exchange. (3) The aspects and characteristics of interdisciplinarity described by project partners and researchers and (4) the role of digitalization accelerated by Covid-19 within EnerSHelF.

After compiling all interviews, the authors re-listened to the recordings to write down comprehensive summaries comprised of edited transcription and information relevant for the

research question. By using the software tool Atlas.ti for qualitative data analysis, the summaries were afterwards evaluated. The reminder logs from the first round of interviews were likewise included. The first step of the analysis involved the coding of passages and quotes to unpack the level of collaboration in the project. By comparing the outcome to the official work plan of EnerSHelF, the thematic breakdown of and trigger for collaboration and exchange is accentuated. In a second step, the codes were grouped to create sets of categories. The answers to the questions, which aimed at dismantling the collaboration frequency of different WPs, were transferred into Microsoft Excel, and added to a contingency table. The contingency table included assigned values for the collaboration frequency of each WP to the other WPs. The categorization is displayed in Table 2 and the individual answers of each interview round presented in the appendix. This pattern of analysis was followed across the set of all four rounds of interviews to achieve comparability of results. By repeating similar questions within the interviews, comparing the answers to those of previous interview rounds, and by interpreting the outcome while considering the context and time of the interviews within the project, the analysis follows a hermeneutic analytical pattern. Despite the transformation of the responses into quantitative data, applying an initial qualitative data collection allowed for flexibility in the answers of the respondents as well as possible adaptations of the questions by the interviewer.

Table 2: Categorization of the Frequency of Collaboration and the Assigned Value

Category	Frequency	Assigned value
Rarely/Never	No contact	0
	Only during official team meetings	
Occasionally	If a specific problem occurs	1
	Less than Monthly	
Peaks	Very close contact during a short period of time	2
Regularly	Monthly	3
	Biweekly	
	weekly	

To display the level of collaboration, the authors propose a collaboration frequency network (CFN). It is based on the participation strength network (PSN), which was developed by Khan et al. (2019) and adapted by Uddin et al. (2021) to measure the relative participation of academic disciplines in ID grant success. Derived from the visualization used for the PSN, CFN is displayed in an adapted network structure with each node presenting a WP of the project, an edge between nodes (shown as a line) represents collaboration of the connected WPs, and the thickness of the line represents the frequency of collaboration. The varying frequencies are categorized as rarely/never (no line), occasionally (thin line), in peaks (dashed line) and regularly (fat line) (see assigned value in Table 2). Darker lines represent broad interdisciplinarity (opposing disciplines) while faded lines are assigned

to narrow interdisciplinarity (close disciplines). In cases, where the answers of WPs regarding the contact they are in differs, the higher value is displayed. In total, there is a 75,82% conformity of the answers. Most differences were neighbouring values (e.g., 1 and 2) and only in three cases it was a bigger discrepancy (e.g., 0 and 2). The size of the nodes is correlated to the CFN of each WP and the colour of the nodes relates to the disciplinary background with red being social sciences, blue being the industry partner, and black assigned to technical, engineering, and natural sciences. The results are visualized with the Microsoft Excel Plugin NodeXL.

For each round of interviews, the collaboration frequency is calculated for all WPs:

$$\mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF_x}} = \frac{\mathrm{E}_{\mathrm{WP_i,WP_j}}^{\mathrm{EnerSHelF_x}} + \mathrm{E}_{\mathrm{WP_i,WP_k}}^{\mathrm{EnerSHelF_x}} + \cdots + \mathrm{E}_{\mathrm{WP_i,WP_n}}^{\mathrm{EnerSHelF_x}}}{\text{Number of WPs interviewed} - 1}$$

where $\mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF_x}}$ is the collaboration frequency of $\mathrm{WP_i}$ within the EnerSHelF project at the time of the interview and $\mathrm{E}_{\mathrm{WP_i,WP_n}}^{\mathrm{EnerSHelF_x}}$ is the assigned value for the edge between $\mathrm{WP_i}$ and the other WPs (derived from interviews) at the time of the interview. In the second step, the collaboration frequencies for each WP at each interview round is aggregated to generate the final CFN:

$$\mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF}} = \frac{\mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF_x}} + \mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF_y}} + \cdots + \mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF_n}}}{\mathrm{n}}$$

where $\mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF}}$ is the aggregated collaboration frequency of $\mathrm{WP_i}$ in the EnerSHelF project (i.e. final CFN). $\mathrm{CF}_{\mathrm{WP_i}}^{\mathrm{EnerSHelF_x}}$ is the collaboration frequency of $\mathrm{WP_i}$ within the EnerSHelF project at the time of the interview and n is the total number of interview rounds considered for the construction of the aggregated CFN. The lowest possible CFN is 0 and the highest possible value is 3.

After calculating the CFN for each WP and interview round as well as the visualization of collaboration, the four interview rounds are compared to see changes in the frequency of collaboration as well as differences between the disciplines.

4. Results

First, the results of the calculation of the collaboration frequency are presented. Second, the collaboration is thematical unfolded. Third, the results of the qualitative analysis of IDR within the project is described. Fourth, the role of the accelerating digitalization is unpacked.

4.1 Collaboration Frequency within EnerSHelF

The collaboration frequency was calculated for each WP and interview round as well as an aggregated CFN. The results are displayed in Table 3.

Table 3: Collaboration Frequency Across Work Packages and Interview Rounds

Work package	**Collaboration Frequency**				**Aggregated CFN**[1]
	1. Interview round	2. Interview round	3. Interview round	4. Interview round	
WP 1.1	0,43	0,71	0,43	0,57	0,54
WP 1.2	0,43	0,71	1,14	0,71	0,75
WP 2	0,71	-	0,43	0,43	0,52
WP 3.0	1,14	1,43	1	1,57	1,29
WP 3.1	1,29	1,43	0,43	1	1,04
WP 3.2	1,14	-	0,43	0,14	0,57
WP 3.3	1,29	1,57	0,86	1,14	1,21
WP 3.4	0,29	-	0,71	1,71	0,90

Lowest possible score = 0
Highest possible score = 3
[1] When WP not included in interview round, the aggregated CFN is calculated on the base of the conducted interviews

In the first interview round, it is observed that the collaboration frequency is clustered across closely related disciplines (faded lines). For example, WP 1.1 and WP 1.2 form the political-economic WPs and work closely together, however, they rarely collaborate with technical WPs (3.0 - 3.4) or the industry partner (WP 2). The technical disciplines collaborate frequently with each other. The exception is WP 3.4, which only has loose contact with other WPs at this time of the project. However, it needs to be stated that WP 3.4 first started their work at EnerSHelF in fall 2020.

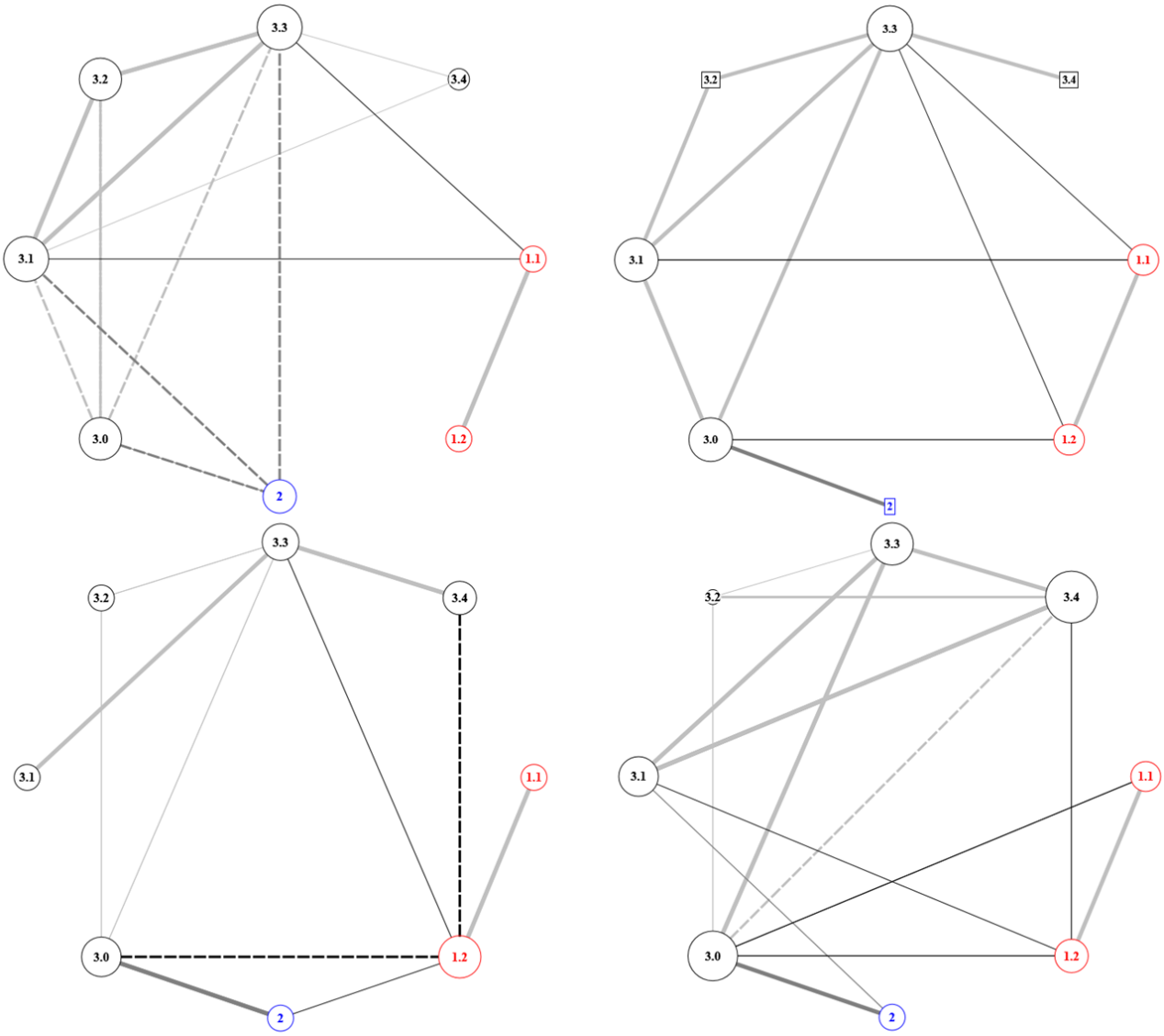
For the second round of interviews, the graph shows minor changes for the included WPs. The technical and natural science disciplines maintained their high level of cooperation while the reported collaboration frequency with socio-economic WPs slightly increased. The industry partner intensified its contact with WP 3.0, but all other connections dropped to rarely/never. WP 3.4 saw an increase in collaboration with WP 3.3 but a drop to WP 3.1. WPs, which did not participate in the interviews, are displayed with squares. However, connecting lines between WPs are undirected, meaning the answers from participating to non-participating WPs are presented, nonetheless. Accordingly, even with the missing data for the second round of interviews, the answers still give an appropriate representation of collaboration. However, there are no insights into the exchange

between WP 2, WP 3.2, and WP 3.4. Again, narrow ID is more frequently observed than broad interdisciplinarity.

Throughout the third round of interviews, a clear shift of the collaboration frequency can be observed. While some WPs maintain a high level, others saw a decline or continuously low level of engagement. Especially across technical disciplines, less collaboration is observed. For instance, WP 3.1 solely maintained regular exchange with WP 3.3 while the frequency of collaboration with the other WPs dropped to rarely/never. A similar tendency can be observed for WP 3.2 and WP 3.0. However, it needs to be stated that just after the second round of interviews, the lead researchers in WP 3.1 left the project and a new colleague took over his position. This discontinuity could have influenced the closeness of cooperation with other WPs, as certain knowledge of possible interlinkages got lost. Contrary, a stronger collaboration is measured between the technical WP 3.4 and the socio-economic WP 1.2. Here, the change was from rarely/never to regular contact. WP 1.2 also intensified its contact with the technical WP 3.0. For the other socio-economic WP, WP 1.1, contact to the technical disciplines dropped from occasional to rarely/never. For the industry partner WP 2, its frequency of engagement with WP 3.0 remained high, while all contact to other WPs remained at a low level. Despite an overall tendency for less collaboration, broad interdisciplinarity intensified between WP 1.2 and WP 3.0 as well as WP 3.4 respectively.

Within the fourth set of interviews, an intensification of collaboration can be observed across nearly all WPs. Especially, across the sub-WPs of WP 3, cooperation increased with a high level of engagement. Solely, WP 3.2 stands out with a comparably lower level of collaboration compared to the other sub-WPs within WP 3. Across the socio-economic work packages WP 1.1 and WP 1.2, the collaboration remained at a high level. Likewise, a numerical increase of cooperation with technical disciplines is measured with WP 1.1 now having occasional contact with WP 3.0. However, the contact of WP 1.2 with other WPs outside WP 1 was less intense than in the previous interview round. It went down from peaks to occasionally. Collaboration with WP 3.3 dropped to rarely/never while contact to WP 3.1 went up to occasional. The industry partner in WP 2 now only has regular exchange with WP 3.0 and occasional contact to WP 3.1. The previous occasional collaboration with WP 1.2 dropped to rarely/never. In terms of the degree of interdisciplinarity, broad ID collaboration decreased as WP 1.2 now has less contact to WP 3.4 and WP 3.0. However, narrow interdisciplinarity increased as shown through the intensified collaboration within WP 3. The collaboration frequency of WPs during each interview round is shown in Figure 1.

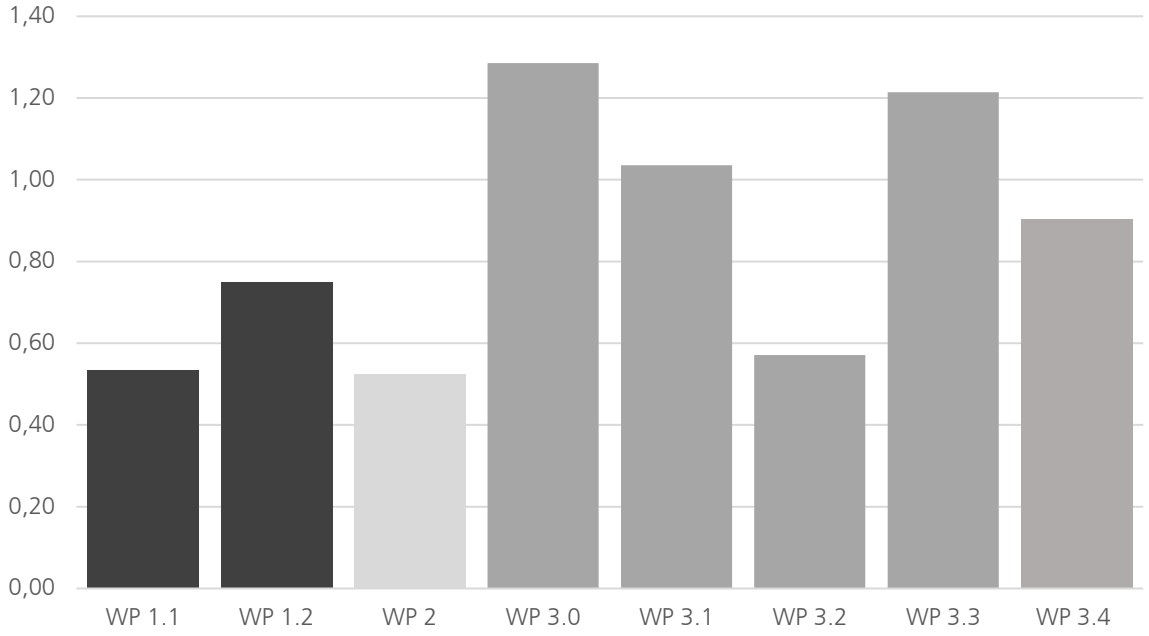
Figure 1: Display of the Collaboration Frequency across work packages and round of interviews



Clockwise, starting in the top left:
1. Collaboration frequency across work packages measured in November-December 2020
2. Collaboration frequency across work packages measured in July - August 2021
3. Collaboration frequency across work packages measured in January - February 2022
4. Collaboration frequency across work packages measured in August – September 2022

Overall, the natural science and technical disciplines have a higher CFN score than the socio-economic WPs (see Figure 2). The industry partner (WP 2) and the extra-scientific institution (WP 3.2) have equally lower scores. However, differences within disciplines are present as well. For example, within the socio-economic WP, WP 1.1 has a score of 0,43 and WP 1.2 0,76. The same can be observed for the natural science and technical disciplines with scores ranging from 0,79 (WP 3.2) and 1,24 (WP 3.3). Overall, the results of the analysis indicate that closer disciplines are more likely to collaborate. However, within WPs, the collaboration of sub-WPs is equally intensive. The differences will be analysed in the upcoming discussion.

Figure 2: CFN of Each Work Package with Colours Representing Different Academic Fields



4.2 Thematic breakdown of collaboration and exchange

Throughout the interviews, certain thematic areas were mentioned as triggers for or are part of conversations and collaboration across WPs. Most mentions circulate around data collection and exchange. Here, the planning of the measurement campaign and the installation of measurement equipment at the field sites were discussed among sub-WPs in WP 3 at an early phase of the project. Later, the storage, distribution, and exchange of data – both of load and meteorological data – became a repetitive trigger for collaboration and was mentioned across all four interview rounds. As the exchange was primarily within WP 3, with exceptional contact to the industry partner, it can be described as narrow interdisciplinarity. The development of the questionnaire for the quantitative data collection and its analysis was leading to knowledge exchange across WP 1.2 and WP 3.4. Based on their disciplinarity distance, this exchange can be seen as broad interdisciplinarity.

Another repetitive trigger were discussions about the development of a load forecasting model as well as an advisor and planning tool for micro grid systems. While the development of such tools was primarily done by independent WPs, input was required from other WPs as well. Cooperation and exchange were described in all interviews and observed during regular work meetings of sub-WPs within WP 3. Again, the closeness of the involved disciplines indicates a narrow form of ID exchange.

The PV-solar hybrid container required ongoing cooperation to ship, build up, operate, and adjust the system. Accordingly, the industry partner has been in contact with the technical disciplines in WP 3 throughout the project as mentioned in all interviews. This includes administrative aspects

such as customs, transportation, and accountability but also technical adjustments and maintenance.

In the context of the field sites and regarding communication with Ghanaian stakeholders, the WPs supported each other. Here, researchers reported of colleagues helping with communication and context-specific cultural insights. This also includes planning travels to Ghana to work at the field sites and solving administrational issues.

When aligning the thematic triggers with the workplan, it is apparent that there is an intersection of what has been reported with the milestones and deliverables for each WP. It needs to be stated that the Covid-19 pandemic disrupted the original work plan of EnerSHelF, which leads to a higher discrepancy of initial work plan and its implementation. Accordingly, a comparison of specific points of the workplan and answers of the interviews is difficult to achieve. However, when looking at timeframes surrounding the date of interviews, there is a noticeable alignment of themes for collaboration in the interviews and the work plan. For instance, the installation of the solar PV container in Ghana at the beginning of the project or the sharing of data during the later interview rounds.

4.3 Aspects surrounding interdisciplinarity within EnerSHelF

Throughout all interview rounds, the interviewees talked about characteristics of and several factors influencing interdisciplinarity within the project. They can be grouped into external and internal factors surrounding interdisciplinarity within the EnerSHelF project and touch upon different aspects.

4.3.1 Internal factors

A major overarching theme throughout internal factors is communication on all levels. Communication is the base for collaboration and cooperation as it includes any form of verbal or non-verbal exchange of information and emerges in many fields of a project. The factors touched upon in the interviews are (1) increased communication and coordination efforts needed to create synergies and cooperation across different academic disciplines, (2) creating regular exchange and creating communication pathways across project partners through regular meetings or seminars, (3) project coordination, (4) organizing TD exchange, and (5) individual factors. Besides these factors related to communication, (6) personal knowledge gain as well as the important role of (7) trust and personal relationship for the researchers and the project are internal factors outlined below.

(1) Throughout the project period, collaboration and cooperation between different WPs was necessary for the development of the measurement campaign for meteorological and load data,

model development, as well as quantitative data collection in Ghana. This asked for ID collaboration, which led to reported delays due to the complexity in communicating and dependencies as it required planning of regular exchange. In one case, it was even reported that the dependency on another WP led to a slowdown of their own research as regular collaboration was a necessity to coordinate data exchange, which had to be planned accordingly. Other practical components of the project, such as the installation of the PV-solar container increased cooperation across disciplines – at least across the technical disciplines. Here, the communication was described as well functioning and not a burden to the process.

To enhance the creation of synergies and consequently collaboration, the establishment of nodes of cooperation was suggested by one of the interviewees. These nodes of cooperation could lead to an entanglement of WPs and would require consistent communication effort by PIs to guarantee and supervise exchange. However, one researcher said that "even the lines where we should collaborate are not so clearly drawn". For instance, for some, it was not clear initially, which data of the other disciplines they could use and realized the potential for cooperation at a later point in the project. Exchange took place rather on demand which led to disciplines without regular work meetings having only intermittent exchange. It would have required a more detailed work plan from the start of the project – something that is also seen as challenging by the interviewees as areas for collaboration might first appear while working but could have been identified earlier through increased communication efforts.

While many interviewees highlight fruitful discussions and exchange with other WPs, they also state that they mostly talk and cooperate to closer disciplines – confirming the analysis of the CFNs. As one of the interviewees put it: "Engineering and economics, yes, they can find a middle line, but the middle line is too far from both ends." Thereby, they see themselves as independent and potential standalone research entities: "All the work packages, we were working in parallel and generating knowledge in parallel – and we are also quite independent from each other." It is highlighted that they are asked by the project lead to deepen communication with other WPs, but it proves difficult at times to achieve it. The lack of regular official work meetings across all disciplines and WPs is seen as a reason. Consequently, some call the project multi- or ID at the same time or even intradisciplinary. Nevertheless, one interviewee claimed that it should neither be the goal to work ID just for the sake of interdisciplinarity.

(2) As mentioned above, creating regular exchange across all project partners was often described as an aspect of interdisciplinarity that requires a close collaboration and communication for it to be effectively established. The initial training workshop at the start of the project was not seen as

sufficient to fully establish a common understanding of what successful IDR is. Especially for those who later joined the project due to a change or nonuniformly employment of project staff, an intermediate workshop with all project partners could have helped to deepen collaboration and integrate communication pathways. Without this, one researcher feared that IDR would become a buzzword in the description of the project and not an integral part of it.

Regular meetings are easier to establish, when all project partners are situated at one institute, however, the nature of IDR often includes different institutions creating a physical separation of researchers. This was described as a barrier to more regular communication and exchange by the project members. To overcome this, a monthly seminar was established with individual researchers presenting their work. Despite PIs' attendance and stimulation of exchange, they are reported to only have had a marginal effect on cooperation across disciplines. Problems that have been mentioned in the seminars and called for cross-WP exchange are seen as seldom picked up by the WPs afterwards – consequently calling it a rather passive than active collaboration. Nevertheless, it was described as an efficient way to understand what the other WPs are working on and to gain insights into their perspectives.

(3) Another internal factor is project coordination. It has been acknowledged by interviewees that IDR needs a binding authority with a strong understanding of all WPs to serve as a link to highlight the added value of cooperation. Here, the role of PIs is seen as both a connector but also monitoring entity to make sure that WPs are communicating and working together. Thereby, it was raised by various interviewees that PIs would need to spend more time on the management of cooperation. They are seen as the ones who should organise regular exchange and push for cross-WP collaboration – using their authority individual researchers don't have towards peers.

It is likewise mentioned that PIs need to guide those inexperienced in working in ID teams. It is described as specifically helpful, if PIs have a background in more than one involved discipline. This was positively perceived in WP 3, where the PI was both a meteorologist as well as engineer. Furthermore, it is also described as PIs' task to set moderate goals and no overly ambitious working plan. However, the interviewees also acknowledged the difficulty of including different actors and disciplines as well as coordinating the change of staff during the project. Especially in an international context, the project coordination requires additional time and effort for management and communication but also flexibility. In EnerSHelF, one colleague was solely assigned to administrative components of the project, which was positively mentioned in the interviewees.

(4) While EnerSHelF has a TD orientation, most WPs report that they haven't been in contact with the industry partner. Others, however, were in regular exchange about the maintenance and

adoption of the hybrid solar-PV system at one of the field sites. Here, it is reported that the industry partner was pro-active in developing solutions. Nevertheless, it is stated by interviewees, that the goal of the industry partner in joining the project were not adequately communicated across all WPs. In the interview with the representative of the industry partner, knowledge-transfer regarding technical aspects and practices such as how renewable energy can be applied adequately to ensure uninterrupted energy supply, as well as project management in the African context were stated as an aim for the company. He thereby reported that different approaches in working procedures need to be communicated well to avoid conflicts. Facing this can lead to intercultural understanding which can be useful for later projects. Originally, it was planned to initiate exchange with relevant stakeholders in the field in both Germany and Ghana to deepen this knowledge exchange. However, due to the Covid-19 pandemic, stakeholder workshops could not be organised until the end of the project, where such an exchange took place during the closing event.

(5) Cooperation of WPs appears to be linked to individual communication capabilities, experiences in working in an IDR team, as well as interest in ID and TD exchange. This can be observed in the regularity of meetings, which strongly rely on individual researchers taking the lead in organising exchange. Furthermore, not all WPs required input from other disciplines, and it was stated that therefor, there was no interest in exchange. Individually, researchers report a good interpersonal communication with their peers from other WPs, especially when interacting during the monthly seminars and other work meetings. Interlinked, most interviewees talked about getting information from other researchers – even from disciplines further apart from their own. Especially when referring to their younger peers, they were described as open-minded towards new ideas.

(6) The interviewees highlighted the individual benefit and personal knowledge gain through IDR and TDR. This is seen to open new questions and to foster learning new skills beyond your own field while communicating across disciplines. Also, it is described that researchers built new connections to their peers abroad and will benefit of their experiences when working in other projects. The affiliated knowledge-exchange was mentioned twice as an important reason to join the project. As an international project, EnerSHelF was described by researchers as a possibility to get out of their own comfort zone while gaining a different understanding of the cultural environment and differences. Overall, it was seen of great value for EnerSHelF, that multiple disciplines were involved: "There is always an added advantage of working across disciplines. You gain extra knowledge, extra skills."

(7) Across the interviews, trust and personal relationships are acknowledged to be fundamental for the success of the project. In one interview, it was stated as a major reason to join the project.

Especially in the international context, well-maintained partnerships across countries arise from trust among partners. For EnerSHelF, the interviewees underline the importance of Ghanaian partners to build up trust to stakeholders in the country. Also, for the day-to-day work, personal relationships are of utmost importance with one interviewee stating that liking each other is an accelerator for cooperation.

4.3.2 External factors

As for external factors, (1) time, (2) the institutional setting (3) academic publications, (4) the long-term effect of the project, (5) international collaboration, as well as (6) the effect of the Covid-19 pandemic were described as characteristic and important factors in shaping the nature of IDR and TDR within the EnerSHelF project.

(1) Time is mentioned in various interviews as a decisive factor for the success of the project. Two train of thoughts are repeated. First, more time is needed to deepen the understanding of other disciplines and to learn from each other. Here, more time at the introductory period of EnerSHelF was seen as missing. Second, the WP solely working interdisciplinarity should have started earlier to develop a well combined and merged working program to facilitate the cooperation of WPs right from the start.

Conclusively, in the last interview round, interviewees stated that they would have needed more time to intertwine the individual results of the WPs. Despite Covid-19, each WP managed to reach their goals, however, a longer project period could have allowed to link the newly generated insights. Some even describe it as a waste of resources if a project period is too short to allow for such a connecting period.

(2) As funded through the Client II initiative by BMBF, EnerSHelF is subject to institutional mechanisms that are seen as hampering for fruitful cooperation – especially in the international context. One aspect is the funding distribution to project partners in Ghana. Interviewees from both Germany and Ghana state that the funding body has an outdated and incorrect perception of Africa and its living costs – especially in urban areas such as Accra. This payment imbalance is seen as creating a hierarchy between project partners. Furthermore, public funding is perceived as not flexible enough for certain settings where down payments might be needed, or expenses exceed initial calculations. This can lead to logistical problems and delays. Time is also mentioned as an additional institutional burden, as the project is bound to the funding period. This leaves insufficient flexibility, which is seen as necessary for cross-country projects.

Other institutional challenges are bound to administrative aspects such as accountability, export controls of equipment, and the shipment of the solar-PV container. Contracts with Ghanaian partners likewise caused difficulties, as it is required by the German funding agency that payments are only made to commercial bank accounts, which are not always present for all partners abroad. Furthermore, the internal structure of universities was seen as unfit or unprepared for such a big international cooperation, which gave EnerSHelF a pioneering role. Overall, it was stated by the interviewees that the difficulties were rather due to the international context than caused by the ID setting. For instance, for the cooperation across different universities, the interviewees reported no specific barriers.

(3) By the time of the interviews, only narrow ID articles involving engineering and meteorological aspects have been published (Chaaraoui et al., 2021), but no broad ID article involving social and technical disciplines. Nevertheless, one interviewee mentioned that a mandatory shared publication by all WPs could have been an accelerator for exchange across disciplines and partners. Another researcher mentioned that he considers the other disciplines when writing his papers, at least in the conclusion by addressing policy makers and not just his academic community.

In one interview it was highlighted that despite working in an IDR project, publishing in your own discipline is of great importance for the researchers' CV – especially when being at the start of an academic career. At the end of EnerSHelF, when all individual WPs finished their work, a cumulative publication is planned by the project lead to bring together the results.

(4) When asked about the long-term effect of the project, it is distinguished between the effect on the involved researchers, field-sites, academia, and the energy and health sector in Ghana. For the latter, it is stated that a future evaluation is needed to measure the long-term effect. The knowledge gain as well as network building are described to have a lasting impact on the involved researchers. The PV-solar container at one of the field sites will be handed over to the Ghana Health Services. Its installation proved to have a positive impact on the electricity stability of the health facility. However, as one of the researchers stated, it is unlikely that it will spread to other clinics due to the remoteness of the site. Within the academic community, one of the PIs observed an increasing interest regarding the effect of dust on PV. Overall, the sum of the single goals is seen to have a possible, positive impact.

(5) For the success of IDR and TDR in an international context, collaboration is of utmost importance. For all WPs, there was a comprehensive agreement that close cooperation of Ghanaian and German project partners was pivotal for the success of their research. However, the funding imbalance had consequences for the level of engagement that the Ghanaian partners were able to provide. While

for some WPs, Ghanaian partners played an important part in the conceptual, methodological, and analytical development of the research, for other WPs the resources for Ghanaian partners were set too low to allow for the time allocation or employment of designated researchers needed for closer involvement. Nonetheless, across all WPs the Ghanaian partners were important gatekeepers to institutions and the cultural environment, which was valued by many interview partners.

(6) Throughout all interviews, project partners mentioned various aspects being influenced by the Covid-19 pandemic. First and foremost, it prevented physical meetings for a large share of the project period, which hampered interpersonal exchange with colleagues and limited the development of a stronger identification with the project. Planned stakeholder workshops in Ghana were likewise forestalled. Furthermore, it had a direct effect on the data collection in Ghana, as equipment was installed with a delay due to logistical challenges regarding the shipment. Despite Covid-19, it is reported that the WPs still managed to get good results and the project extensions allowed for a successful finalisation of EnerSHelF.

4.4 Accelerated role of digitalization

Since March 2020 almost all work meetings within the EnerSHelF project took place online and only a few research trips were possible due to Covid-19 travel restrictions. Accordingly, many work packages experienced an increased reliance on digital tools and communication within their work. During the second round of interviews, the project members were asked about both advantages and disadvantages of the increased digitalization within EnerSHelF. Within their answers, three main areas were touched upon: (1) data collection, (2) setup and maintenance of equipment at the field sites, as well as (3) individual aspects and interpersonal communication. Furthermore, insights from the other rounds of interviews are also taken into consideration to shed light on the aspect of interdisciplinarity.

For the quantitative data collection, the original plan was to arrange a training in Accra for local enumerators for the conduction of 200 interviews at health facilities in Ghana. The training had to be moved online, which was generally seen as a disadvantage. However, a positive effect was that the enumerators, who were scattered across Ghana, were able to join the training remotely. Another disadvantage regarding interviews in Ghana was that it proved difficult to schedule online appointments with policy makers. Nevertheless, despite the travel bans, it was possible to conduct most of the scheduled interviews with the help of digital tools and meetings.

One of the major challenges of the project was to setup and maintain measurement equipment and the PV-hybrid container at the field sites as German project partners were unable to travel to Ghana during a period of closed borders. Most of the work had to be coordinated digitally with

local partners and external Ghanaian contractors. This mode of practice was prone to errors. However, smaller adjustment at the sites could be done more quickly with the help of online communication – when working smoothly.

Another aspect of the increased role of digitalization is the personal interaction with the other teammates. While some of the researchers see an overall improvement by the low threshold of online communication to get into contact with their peers abroad, it is also stated that it is more difficult to build up relationships to the other project members. Furthermore, the motivation for online meetings is often seen as missing. However, On the individual level, the enhanced digitalization is seen as a chance to learn new modes of working and problem solving.

Regarding the ID exchange across WPs, the digital mode of practice – enforced by the Covid-19 pandemic – also led to a reported decrease in cooperation across disciplines. One team member stated that he was less in contact with the other WPs in time of travel restrictions. Another project partner stated that "reduced contact, because of the current situation [Covid-19], has […] also impacted [… the] angle of cooperation". It is also likely to have impacted the level of identification with the project, as personal exchange was limited to online meetings for most project partners.

5. Discussion

While many publications on the nature of IDR describe the potential and possible barriers, this paper analysed the frequency and scope as well as the thematic breakdown of collaboration of involved disciplines. Furthermore, the characteristic of and factors influencing IDR and TDR – both internally and externally – in the EnerSHelF project were examined.

Throughout the data collection and analysis, certain limitations became apparent. First and foremost, the comparability of the interview rounds was aggravated due to the different number of interview partners in each round as well as change in personal during the project. Though, by using semi-structured interview guidelines and by quantifying the results for the CFN, the authors are confident that the results are giving an adequate interpretation of the nature of IDR within the project. However, despite the aim to objectively analysis the interviews, the results are influenced by the authors' interpretation. By quantifying a part of the insights of the interviews, the authors aim to mitigate against this flaw. Furthermore, another limitation is the nature of qualitative data collection itself: While the results where quantified through the CFN and the questions designed to get objective, comparable results, the base data builds on subjective answers and researchers' memory of exchange. This explains the differences in replies regarding the collaboration frequency between WPs. However, the 75,82% uniformity quota in answers to inter-WP exchange suggest a good validity of results. This is additionally backed by consistently using the higher score as the benchmark for the undirected display of exchange.

Despite the limitations, the results of the analysis mirrors many of the characteristics and factors influencing IDR and TDR identified in previous studies such as communication (Bracken & Oughton, 2006; Pedersen, 2016; Tobi & Kampen, 2018), time (Heberlein, 1988; Klein, 2008; Halvorsen et al., 2016; Pedersen, 2016; MacLeod, 2018), institutional barriers (Blättel-Mink et al., 2003; Institute of Medicine (U.S.), 2005), publications (Fischer et al., 2011), or North-South hierarchy (Schmidt & Pröpper, 2017). This section recourses to the literature, and by looking at six main insights derived from our analysis, offering a context-specific discussion.

First, the authors identified a higher frequency of collaboration determined by disciplinary closeness of WPs within the project. Looking back at literature on IDR, it is likely to be explained by shared methods, data, and language, which make it easier to communicate with closer disciplines (Pohl, 2011; Pedersen, 2016). In the interviews, it was apparent that intertwined research designs likewise let to regular collaboration due to the necessity for exchange of data. When looking back at the measured level of collaboration, a substantially higher CFN score is observed for researchers in WP 3. As there are more technical than socio-economic WPs involved in the project, this is not a surprise.

Accordingly, it does not indicate a lower intensity of collaboration across closer disciplines. However, it indicates that narrow ID was more likely to occur. Despite the higher frequency of collaboration for closer disciplines, personal knowledge gain due to the contact to the broad variety of academic fields is described across all WPs. The acceleration in understanding other disciplines and opening up new perspectives is a central advantage of IDR (Jahn et al., 2012; Pipere & Lorenzi, 2021). Furthermore, contrary to arguments brought up in the literature (Bracken & Oughton, 2006), the interviewees perceived the ID work mainly as an opportunity for personal and professional growth and not as a career barrier.

Second, our analysis shows that collaboration doesn't happen automatically but requires an integrative planning approach. As described by Holm et al. (2013), ID collaboration is often not an integrated reality right from the start of a project. Here, organising collective trainings throughout the project with all involved partners and researchers can have an integrating effect (Zinsstag et al., 2011; Halvorsen et al., 2016; Piso et al., 2016; Pischke et al., 2017). The advantage of having a distinct introductory training is described by Pischke et al. (2017) to establish a common understanding of the project's aim and the other disciplines. It can be argued that the potential for collaboration was not exploited to the fullest in the EnerSHelF project, as interviewees stated that some areas of possible ID exchange were unknown at the start of the project. Here, regular meetings distinctively designed for the identification of collaboration could have initiated an enhanced understanding of what other disciplines need in terms of data and where cooperation is a potential asset. The monthly seminar could have taken such a role, however, attendance varied, and questions to the presenters often arose from closer disciplines – leading to no broad ID Q&A. Furthermore, it was reported that topics discussed during the seminar as possible areas for collaboration were seldom picked up by the researchers afterwards. Garwood and Poole (2018) show in their research that PIs should enhance the collaboration after such meetings and integrate it in the working plan. Another possible intervention is a predefined list compiled by PIs, which states potential questions that one discipline could have to others. This can be a guideline for researchers to identify areas for cooperation and can be updated regularly. The management interventions to improve ID integration as proposed by Bark et al. (2016), however, seem partially applicable for broad interdisciplinarity. Nevertheless, fostering intra-project communication and building-in organisational learning are recommendable for PIs to focus on.

Third, our analysis shows that cooperation of WPs oscillates depending on the workload and personal initiative. During the project period, the level of collaboration was intertwined with working steps such as data collection and sharing, or installation of equipment in Ghana. Within the interviews, researchers reported an intensified contact to other project partners when there was

a need of exchange but not due to curiosity for the other WPs' work. This allows for the assumption that PIs should specifically look for candidates who are interested in engaging with other disciplines. Hence, it is advised to follow Milman et al. (2017) argument that the intrinsic motivation of researchers should be considered when planning an IDR project. To guide cooperation away from intrinsic motivation, an institutionalised, regular exchange across WPs could have led to further collaboration. Despite the mention of regular meetings in the workplan and impulses by PIs to seek exchange, interviewees mentioned that they were only in contact if they independently initiated meetings. Halvorsen et al. (2016) reported that a weekly to monthly video and in-person meeting is well received by researchers of TDR projects. The monthly seminar was likewise well received – at least to the degree that it informed the WPs of the current work of their peers (Haas & Hellmer, 2014). Additionally, it is stated that successful collaboration between researchers is influenced by their previous experience of working together as it counterbalances "negative impact of distance and disciplinary differences" (Cummings & Kiesler, 2008). On the other hand, researchers leaving a project can have a discontinuing effect on collaboration across disciplines (Garwood & Poole, 2018). For EnerSHelF, however, the interviewees felt that especially younger team members were open for new input from other disciplines. Nevertheless, an intensified engagement with more experienced researchers could have led to "effectively harness the contribution of the full team", as argued by Bammer et al. (2020).

Fourth, the international and ID characteristic of EnerSHelF led to a greater complexity to manage the project. This boils down to aspects such as funding requirements, contracts, export regulations, and additional temporal effort to communicate across different institutions and borders (Halvorsen et al., 2016). In EnerSHelF, one project employee was solely working on management aspects. During the interview, she reported that she had to do pioneering work when it came to dealing with requirements in place by the lead institution. This will be specifically valuable for future international projects and strengthens the argument made by Bark et al. (2016), that granting both time and resources is essential for the success of a project and can foster organisational learning. However, the collected experiences need to be institutionalized. In case these people leave the institution, this knowledge will be lost.

Fifth, the Covid-19 pandemic added a new layer of complexity to the project. While digital communication in international projects has been an important tool for communication across countries and continents (Pischke et al., 2017), it became the only option for communication during the global lockdowns. This led to an increasingly difficult fieldwork setting, which had to be managed carefully by working closely with local partners. Despite the extra effort it required, the digital working methods had the advantage to break down physical barriers for meetings: Ghanaian

project partners were able to join in any work meetings in Germany at any time. Overall, EnerSHelF was a product of its time with an accelerated digital component due to the Covid-19 pandemic, which posed both a challenge but also opportunity. However, it prevented the project partners to build up close personal relationships with their peers as physical meetings were suspended as a binding and trust-building link. In the literature, the importance of trust is highlighted as a way to mitigate or solve multiple barriers (Lakhani et al., 2012; Allen et al., 2014; Pischke et al., 2017; Schmidt & Pröpper, 2017). Trust can be established through interactive experiences with the help of "team and trust-building exercises" beyond work meetings (Pischke et al., 2017). These were prevented by the Covid-19 pandemic, however, the EnerSHelF project was found on previously established relationships between Ghanaian and German partners which extenuated the possible negative effect.

Sixth, a power imbalance between German and Ghanaian partners was apparent throughout the project. North-South power hierarchies are a known problem within international research projects (Schmidt & Pröpper, 2017). For EnerSHelF, the imbalance was due to donor requirements set through the Client II funding line. Hence, Ghanaian partners were only permitted as associated partners during the project. This included a comparatively low payment to and budget for Ghanian partners – which were not directly transferred by the German donor organisation but had to be sent through the administrative bodies of the German universities. This design flaw and disproportion towards international partners can lead to a lack of commitment by the associates as described by Schmidt and Pröpper (2017). A Ghanaian project partner put it blandly in one of the conducted interviews: "It boils down to the motivational factors and comes back to the budget issue."

Looking back at the initial question whether EnerSHelF can be seen as ID, respectively TD, or should be described as a multidisciplinary project, the answer is twofold: the project's composition was ID, however, mostly narrow ID. According to Barthel and Seidl (2017), IDR means an intense collaboration from project definition to methodology to evaluation of results. Throughout the four rounds of interviews, the intensity of collaboration varied but never dropped to zero. Nevertheless, the perception that each WP could have reached their goals independently was expressed across many interviews. Despite this, IDR should not be performed for the sake of ID but needs to be seen as a combined effort to answer research questions, which cannot be answered by a single discipline. This overarching and holistic approach is often described as the main advantage of IDR (Pérez Vázquez & Ruiz Rosado, 2005; Allen et al., 2014; Hans, 2015; Arnold et al., 2021). The described continuous collaboration throughout the project shows that it was indeed ID and can be described as narrow ID.

6. Conclusion

IDR and TDR do not 'just happen', but ask for attentiveness and motivation from PIs, partners, and researchers. Despite the long history of IDR and TDR in academia and the awareness of interlinked challenges, this article shows that its success is not granted but requires great effort. With the analysis of the international project EnerSHelF, the authors intend to offer a context-specific discussion of IDR and TDR. Throughout four interview rounds, thematic triggers for collaboration, the collaboration frequency across WPs measured with the adapted CFN framework, the accentuated role of digital tools, as well as internal and external factors and characteristics of IDR were identified. The analysis shows that closer disciplines are more likely to cooperate, and that the intensity of collaboration oscillates throughout the project. To foster exchange of further apart disciplines in future research projects, a set of learnings can be derived from the analysis and discussion of results. Many of these learnings are directed at project management but also towards institutional recommendations. Seven suggestions are presented below:

1. Nodes of cooperation: Establishing nodes of cooperation can link the different disciplines from the start of the project and help to set a continuous flow of collaboration across the project period.
2. Interdisciplinary training: Organising regular ID training sessions throughout the project for all researchers can establish a common understanding of where and how to cooperate.
3. Combined work packages: Establishing a work package which combines questions from all involved disciplines to serve as a catalysator for different disciplines to work together.
4. Common goal: Strengthening the awareness of working towards a shared goal can be achieved through workshops and regular information exchange among the disciplines.
5. Develop trust: Allocating time and resources on the development of trust among the project members is likely to increase communication among the included disciplines and subsequently ID collaboration.
6. Adapt funding scheme: Adapting the funding mechanism to allocate resources equally can level the hierarchy between German and international partners.
7. Longer project periods: Exceeding the standardized three years of many publicly funded research projects is likely to generate a more sustainable impact.

IDR and TDR are placed in context-specific environments and require adopted frameworks and guidelines. However, certain characteristics and challenges are shared among IDR and TDR projects alike. The results of this paper and the developed suggestions aim to provide a starting point in planning future projects and adds to the rich body of literature.

Appendix

Tables – Frequency of Collaboration Among Work Packages

1. Interview Round (November & December 2021)

Work package	WP 1.1	WP 1.2	WP 2	WP 3.0	WP 3.1	WP 3.2	WP 3.3	WP 3.4
WP 1.1		3	0	0	0	0	0	0
WP 1.2	3		0	0	0	0	0	0
WP 2	0	0		1	2	0	2	0
WP 3.0	0	0	2		2	2	2	0
WP 3.1	1	0	0	2		3	3	0
WP 3.2	0	0	0	2	3		3	0
WP 3.3	1	0	0	2	3	3		0
WP 3.4	0	0	0	0	1	0	1	

0 = Rarely/Never (Only during official team meetings/no contact)
1 = Occasionally (If a specific problem occurs/less than monthly)
2 = Peaks (Very close contact during a short period of time)
3 = Regularly (Monthly/Biweekly/Weekly)

2. Interview Round (July & August 2021)

Work package	WP 1.1	WP 1.2	WP 2	WP 3.0	WP 3.1	WP 3.2	WP 3.3	WP 3.4
WP 1.1		3	0	0	1	0	1	0
WP 1.2	3		0	1	0	0	1	0
WP 2	/	/		/	/	/	/	/
WP 3.0	0	1	3		3	0	3	0
WP 3.1	0	0	0	3		3	3	0
WP 3.2	/	/	/	/	/		/	/
WP 3.3	0	0	0	3	3	3		3
WP 3.4	/	/	/	/	/	/	/	

0 = Rarely/Never (Only during official team meetings/no contact)
1 = Occasionally (If a specific problem occurs/less than monthly)
2 = Peaks (Very close contact during a short period of time)
3 = Regularly (Monthly/Biweekly/Weekly)
/ = No interview took place

3. Interview Round (January & February 2022)

Work package	WP 1.1	WP 1.2	WP 2	WP 3.0	WP 3.1	WP 3.2	WP 3.3	WP 3.4
WP 1.1		3	0	0	0	0	0	0
WP 1.2	3		1	1	0	0	1	2
WP 2	1	1		3	0	0	0	0
WP 3.0	0	2	3		0	1	1	0
WP 3.1	0	0	0	0		0	3	0
WP 3.2	0	0	0	0	0		3	0
WP 3.3	0	0	0	1	1	1		3
WP 3.4	0	2	0	0	0	0	3	

0 = Rarely/Never (Only during official team meetings/no contact)
1 = Occasionally (If a specific problem occurs/less than monthly)
2 = Peaks (Very close contact during a short period of time)
3 = Regularly (Monthly/Biweekly/Weekly)

4. Interview Round (November & December 2021)

Work package	WP 1.1	WP 1.2	WP 2	WP 3.0	WP 3.1	WP 3.2	WP 3.3	WP 3.4
WP 1.1		3	0	1	0	0	0	0
WP 1.2	2		0	1	1	0	0	1
WP 2	0	0		2	1	0	0	0
WP 3.0	1	1	3		0	1	3	2
WP 3.1	0	0	1	0		0	3	3
WP 3.2	0	0	0	1	0		0	0
WP 3.3	0	0	0	3	3	1		1
WP 3.4	0	1	0	3	3	2	3	

0 = Rarely/Never (Only during official team meetings/no contact)
1 = Occasionally (If a specific problem occurs/less than monthly)
2 = Peaks (Very close contact during a short period of time)
3 = Regularly (Monthly/Biweekly/Weekly)

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