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Integrated Policy Package Assessment (IPPA): A Problem-Oriented Research Approach for Sustainability Transformations

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Abstract: In this paper, we present the Integrated Policy Package Assessment (IPPA) approach and relate IPPA to three substantial concepts of problem-oriented research concerned with societal transformations: technology assessment (TA), sustainability research (SR), and responsible research and innovation (RRI). The IPPA approach provides (political) decision-makers with transformation and orientation knowledge via a four-step process of (1) design, (2) analysis, (3) evaluation, and (4) discourse of a policy package assessment. It is illustrated with a case study of urban passenger transport. As an integrated approach, IPPA has substantial ties to TA, SR, and RRI. It connects with TA in fundamental ways, since it combines the field of TA with the field of regulatory assessment based on consequence analysis. Connectable to the field of SR, IPPA addresses deliberation processes and sustainable pathway identification based on multi-criteria assessment. In addition, akin to the area of RRI, IPPA shows cross-cutting axes with regards to social resonance assessment and stakeholder evaluation with a focus on multi-actor responsibilities. In this contribution, we link evidence-based impact assessment with transformation pathway mechanisms and corresponding policy packages, backed by stakeholder-based responsible innovation feedback loops. This enhances the ex-ante analysis of policy packages regarding their intended as well as unintended consequences.

Keywords: policy packages; integrated impact assessment; technology assessment; sustainability research; responsible research and innovation

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1. Introduction

The transformation of the energy system has become a high-ranking priority on the political agenda in many countries. In response to climate change challenges, the main emphasis is on transitioning the energy system from high- to low-carbon or even carbon-neutral energy supply. The German energy transition is first and foremost based on political decisions since promising transformation pathways towards a climate-compatible future can largely only be realized through political intervention and adequate policy action. In short: no decision—no transition. However, a key question for political decision-makers is which decisions should be taken to realize adequate transformation paths. Decisions need to consider both the intended and unintended effects against the background of alternative decisions, which may reach the same transition target but show different impact consequences (in short: decision–transition–impact chains). In order to make the diverse effects of individual policy measures visible in advance of their implementation, we introduce what we believe is an essential interdisciplinary approach to analyzing socio-technical energy futures. The assessment of future-oriented pathways and corresponding policies is based on an array of hypothetical ex-ante assumptions such as future developments of specific technologies, actors, or individual decision rationalities, as well as uncertainties such as disruptive events in an area of complex socio-technical systems [1]. Against this background, the main research questions that we asked were:

- How can promising transformation paths for the energy transition and their underlying policies be methodically identified?
- How can they be assessed coherently using inter- and transdisciplinary research regarding their intended (and unintended) effects?

The authors have identified a lack of approaches to combine the qualitative and quantitative results of ex-ante impact analyses of policies into an overall picture. In addition, the impact of policies is often only examined for individual instruments, rather than for their overall impact within a policy package. Taking the decision–transition–impact chain as a leading principle, in this paper we contribute to closing the research gap through the conceptual development and empirical implementation of what we call an Integrated Policy Package Approach (IPPA). This approach provides (political) decision-makers with transformation and orientation knowledge via a four-step process of (1) design, (2) analysis, (3) evaluation, and (4) discourse of the policy package assessment. The main goal was to ex-ante analyze different transformation paths and the possible corresponding policy packages regarding their intended as well as unintended consequences. We applied this conceptual approach through focusing on a case study of urban passenger transport as an illustrative example [2,3]. The methodology was developed for the prospective analysis, assessment, and evaluation of the effects and side effects of technological, economic, political, legal, or social policy options which aim to further implement the mobility transition as part of the German energy transition (Energiewende) towards ambitious climate-friendliness and sustainability. The work was carried out within a nationally funded research project (acronym ENavi) [4,5] under the umbrella of a focus topic of 'sustainable transport and mobility'.

In this paper, we relate IPPA to three fundamental concepts of problem-oriented research concerned with societal transformations. We use the research activities and findings of our case study carried out in ENavi to illustrate the ways in which IPPA shares practical and epistemological features and interlinkages with these concepts. The three concepts are technology assessment (TA), sustainability research (SR), and responsible research and innovation (RRI), which have been key research fields for some decades. TA emerged in the early 1960s in the US and has since served as a science-based policy advice approach to assessing the impacts of technologies. SR has become a popular cross-sectional research science discipline following the Brundtland Report in 1987 [6]. RRI has been promoted by the European Commission and gained increased attention and visibility around 2010. This article details common cross-cutting axes and similarities between IPPA and TA, SR, and RRI. In our view, IPPA exemplifies and operationalizes important claims and demands entailed by these approaches, and, as such, it can be seen as a practical research procedure which incorporates the key principles of TA, SR, and RRI.

The paper is organized as follows: Section 2 reports on the materials and methods that were applied in ENavi and the corresponding case study and sketches the methodological concepts and procedure of the IPPA approach. Section 3 presents the results and contrasts IPPA with the three concepts of TA, SR, and RRI. For each concept, we deduce its corresponding key features and specify its linkages and implementations within the IPPA approach. Section 4 provides a discussion of the results on a more generic level and draws some conclusions.

2. Materials and Methods

The development of IPPA relied on several qualitative and quantitative methods and material from different disciplines, developed in the research project ENavi. In this section, we first explain the broader research context and describe IPPA as a generic assessment model, its elements, and the procedure for applying it. In a second step, we explain the methods and material, that is, a pool of contributing impact studies that were used when applying IPPA empirically to the example of urban passenger transport.

2.1. Broader Research Context: The ENavi-Project and the Case of Urban Passenger Transport

The IPPA approach was developed within the research project "Kopernikus Navigation System for the Energy Transition (ENavi)" (2016–2019). ENavi gathered a wide range of technical, economic, and social science expertise in the field of energy research. The consortium united 58 alliance partners (23 research institutes, 18 university institutes, three non-governmental organizations, nine companies, three local authorities, and two regional authorities) that worked together in 13 thematic work packages. In addition, 25 associated expert partners contributed their practical experience to the topics of energy-related infrastructure, heating, and mobility (cf. Table 1). The project aim was to develop and implement an inter- and transdisciplinary approach to integrate political interventions and measures and work across the energy sectors of electricity, heat, and mobility. The work packages contributed their respective research results as individual elements in the overall approach.

Table 1. Number and diversity of project participants in the large-scale project Navigation System for the Energy Transition (ENavi).

58 Alliance Partners	25 Associated Practitioners [1]
• 23 research institutes • 18 university institutes • 3 non-governmental organizations • 9 commercial enterprises • 3 public utilities • 2 local authorities	• 9 service, consulting, coordination organizations [2] • 7 commercial enterprises • 3 civil society organizations • 2 research institutions • 1 trade union organization • 1 public utility • 1 transport association • 1 trade association

[1] Expertise in the areas of infrastructure/grids, heat/buildings, mobility. [2] Private and public in the areas of energy transition, law, business development, mobility. Source: [7], translation by authors of this paper

One major focus of ENavi was the defossilisation of transport and mobility as part of the transformation of the overall energy system towards climate neutrality and sustainability. Within this focus, we conceptually developed and empirically implemented the IPPA approach using a case study of urban passenger transport. For this purpose, researchers from various disciplines conducted separate studies, with a focus on innovation economics, energy economics, institutional economics, social science, environmental science, environmental psychology, and law, analyzing different intended (and unintended) impacts of a policy package which we describe in detail in Section 2.2.

The defossilisation of the transport sector, in the sense of independence from fossil fuels, together with a significant change in mobility behavior is one of the major challenges regarding the energy transition. An inter- and transdisciplinary package of policy measures that takes up this challenge is central to the priority topic of transport. Problems and solution approaches differ significantly from one transport area to another, and cross-sector solutions for diverse areas, such as urban passenger traffic, freight traffic, or air traffic, are of limited use. Urban passenger transport in core cities and densely populated surrounding areas was, therefore, chosen as a priority case study for our analysis, developing and applying the IPPA approach.

2.2. The Methodological Procedure of the IPPA Approach

The main idea for IPPA was to develop an assessment procedure that delivers system knowledge, transformation knowledge, and orientation knowledge on functionally equivalent policy packages which aim to implement intended future pathways towards climate-friendliness. In that sense, the IPPA method operationalized the leading principle of the decision–transition–impact chain. Within the research on urban transport, we detailed the methodological process into a four-step phase model, consisting of the steps of (1) design, (2) analysis, (3) evaluation, and (4) discourse (cf. Figure 1).

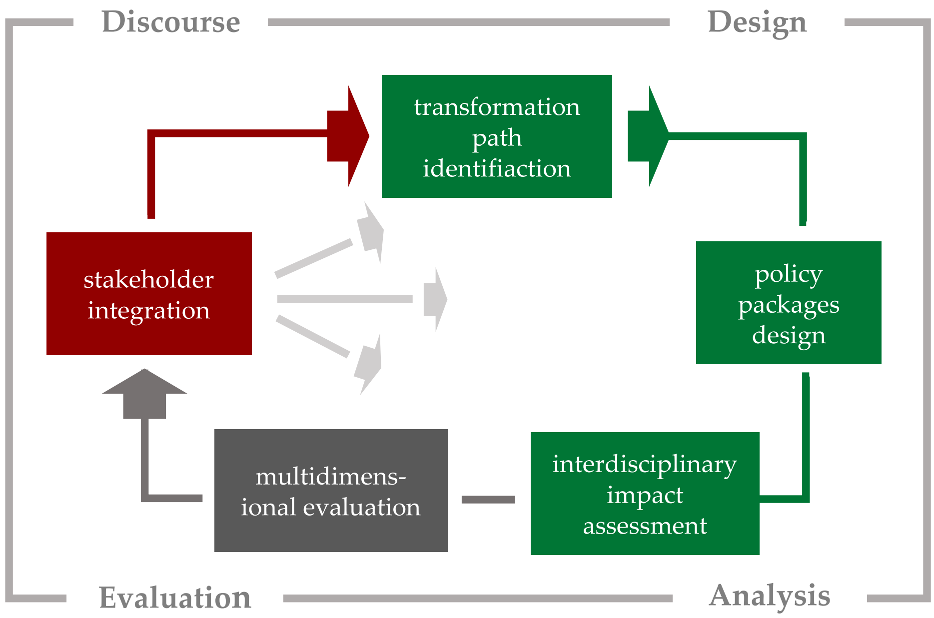

Figure 1. Ideal-type Integrated Policy Package Assessment approach. Source: adapted from [8].

(1) Design means putting several policy measures and interventions into a bundle: a coherent policy package. The policy packages were developed using a mixed-method design comprising (1) a literature review in which an inventory of potential measures based on scientific studies was compiled, (2) a participatory Group-Delphi workshop [9–11], in which the inventory of measures was checked for plausibility, supplemented, and an initial design of the policy packages was created, and (3) a stakeholder workshop in which practitioners reviewed the policy packages and their potential effects that deal with these issues in practical implementation.

According to the literature on the policy package approach, the following key elements define a package: (1) It includes one (or more) core policy measure(s) in combination with (2) ancillary measures. The core measure effectively stimulates the intended transformation mechanisms and/or is socially or politically as uncontroversial as possible. The ancillary measures have three rationales: They either increase the effectiveness of the core measure, strengthen the acceptance of the core measure, or facilitate political support for the core measure [12–15].

(2) Analysis means an interdisciplinary impact assessment in which the various effects of policy packages are assessed ex-ante from different disciplinary perspectives. For this purpose, the policy packages and their design elements were made available by IPPA coordinators to the ENavi scientists in a synthesis paper. On this basis, each disciplinary ENavi scientist team conducted its impact analysis bottom up in an independent first step. Although the ENavi scientists received, from IPPA coordinators, a qualitatively organized analytical scheme to use as orientation in their study, emphasis was placed on the greatest possible openness in the research process at this stage, and, therefore, the step of synthesis and comparison was carried out in the next step, in the course of the evaluation.

(3) Evaluation means a synthesis of assessment outcomes into a multidimensional framework. On an empirical level, this means bringing the disciplinary analyses of the possible impacts of the policies and the policy package together to form a consistent picture. At this point of the IPPA, it is important that qualitative and quantitative results are combined. The result is a mosaic-based picture consisting of qualitative and quantitative data, which is used as the basis for the next step.

(4) Discourse comprises a dialogue-based exchange and review by practice actors and other stakeholders. It refers to the transdisciplinary approach in the IPPA, i.e., stakeholders are involved at all steps of the IPPA process, in order to integrate feedback loops continually. In our case study, the methodological process specified the overarching objective of integrating and synthesizing heterogeneous impact assessments of policy measures, including the reflections of practice actors and other stakeholders, as a joint application-oriented research endeavor. This step is not to be understood as a fourth step in a chronological sequence; rather, the transdisciplinary embedding has to take place within the design, analysis, and evaluation phase. A schematic description of the step-by-step procedure in the application of the IPPA approach is summarized in Table 2.

Table 2. Schematic procedure for applying the IPPA approach.

DESIGN: Identification of the transformation path(s) and design of policy packages	**Transdisciplinary research approach:** Continuous involvement of stakeholders in various formats (workshops, Delphi groups, interviews, etc.)
Determination of the transformation path and its target system 1. Transformation objective(s) to be achieved with policy package 2. Outline of the transformation path with its framework conditions *Compilation of existing and possible future policy measures and analysis of the causal relationships* 1. Selection of a core measure that (1) is as uncontroversial as possible or (2) contributes to the highest possible extent to the goal achievement 2. Selection of ancillary measure(s) (that either increase impact or effectiveness or reduce unintended effects or strengthen acceptance)	
ANALYSIS: interdisciplinary impact assessment of policy package measures	
1. Analysis and impact assessment of (core) measures with accompanying measures by different disciplinary studies (e.g., ecological, economic, technological, social, behavioral impacts)	
EVALUATION: Impact assessment of the policy package	
1. Explicit consideration of interactions as well as intended and unintended effects of the policy measures 2. Synthesis of singular impact results into a multicriteria assessment framework	
DISCOURSE *: Deliberation process of the policy package and its impacts	
1. Discussion of research results with actors from practice and science (regarding design and bundling of policy measures, impact assessment results on policy impacts) 2. Exchange and brainstorming on political and practical issues (e.g., policy sequencing, important impulses for politics, etc.)	

Source: own elaboration; * Discourse is listed here as the final step, but this is not to be understood sequentially, rather in the sense of a transdisciplinary research approach as a continuous and important element from the beginning onwards (see also Section 3).

3. Results

3.1. The IPPA Approach in Practice

Within our research, the IPPA approach was applied as a case study in the field of urban transport. We designed two complementary policy packages that were capable of triggering two transformation pathways, of "multi- and intermodality" and "alternative drive systems", within the system boundaries of urban passenger transport. Shifting the modal split away from motorized private transport (MPT) and substituting combustion engines in passenger cars and other transport carriers with alternative drive technologies, such as electric drives, are widely seen in the literature as promising and complementary pathways towards sustainable transport. The starting point for the *design* of the policy packages was an inventory of measures based on system-analyses studies on the energy and transport transition [2]. In particular, the study by Zimmer et al. (2016) [16] revealed to be crucial. The study is based on the framework data of the Federal Transport Infrastructure Plan and the climate protection scenarios 2050 and is the only study known to the authors at the time of the analysis that achieves complete climate-neutral mobility by 2050 with different scenarios. In this paper, we take the policy package "alternative drive" as an example to illustrate the implementation of the IPPA approach. The detailed alternative drive policy package measure description is depicted in Table 3.

Within the analysis phase, the assessment of the policy package comprised a wide variety of single impact studies developed by the contributing ENavi scientist research groups. These were all equally important, since each study's method is characterized by specific strengths and weaknesses, and only their combination leads to robust results. Thus, for example, parallel literature analyses, expert surveys, dialogues with practice actors, scenario-based transport system analyses (simulation and optimization models), etc., were included in the contributing studies. An overview of the contributing impact studies can be found in Table 4.

Table 3. Policy package "Increase of alternative drive systems via CO_2 emission performance standards, and a CO_2 price component for fossil fuels" (Short: "alternative drives").

Core measure 1: "CO_2 emission performance standards of 60 g/km by 2030"

- What: Setting a fleet limit for newly registered vehicles in Europe (starting value 95 g/km in 2020, reduction to 60 g/km by 2030); closing the current gap between the standard value (New European Driving Cycle, NEDC) and the real value of about 40%.
- Objective: To increase the supply of vehicles with alternative drive systems
- Type: regulatory policy measure

Core measure 2: "CO_2 price component for fossil fuels"

- What: Introduction of a CO_2 price component for fossil fuels that ensures the mathematically necessary increase in user costs of 2% p.a. from 2010 to 2030. For petrol, a total sum of 83.7 ct per liter from the mineral oil tax and the CO_2 component must be achieved in 2030; for diesel, a total of 89.2 ct per liter. Setting the CO_2 price component at €150 per t of CO_2 in 2030 (equivalent to 36.7 ct per liter of petrol and 39.6 ct per liter of diesel). At the same time, adjustment of the mineral oil tax: for petrol, reduction from today's 66.96 ct/liter to 47 ct/liter; for diesel, increase from today's 46.38 ct/liter to 49.6 ct/liter.
- Objective: To reduce the attractiveness of conventionally operated vehicles by increasing variable costs (costs of use) by 2% p.a. (2010 to 2030)
- Type: economic policy measure

Ancillary measure 1: "Reform of the motor vehicle tax"

- What: Conversion of the motor vehicle tax to CO_2 emissions as the sole assessment variable. The tax exemption for electric vehicles remains in place. Up to a limit of 95 g, 0.40 Euros per gram will be charged, and, from 96 g/km to 115 g/km, 0.80 Euros per gram. Between 115 and 135 g/km, 2.00 Euros per gram will be charged, and over 136 g/km, 5.00 Euros/g will be charged. Above 200 g/km, the amount per gram of CO_2 rises to 15.00 Euro.
- Objective: To further reduce the attractiveness of conventionally powered vehicles by increasing the fixed costs (maintenance costs) for vehicles with fossil-fueled drives
- Type: economic policy measure

Ancillary measure 2: "Technology development for intelligent charging points & tariff systems"

- What: The ongoing development and expansion of the public charging infrastructure (= charging points in public spaces that can be provided by public or private actors) will be continued and supplemented by encouraged technology development, which aims for solutions for intelligent, network-related charging, taking into account, e.g., adequate tariff systems.
- Objective: Unproblematic integration of charging processes into the electricity system, avoidance of user restrictions
- Type: promotional policy measure

Table 3. *Cont.*

Ancillary measure 3: "Guideline on parking fees"
• What: The objective of this measure is the gradual and transparently announced increase in parking costs by 50% by 2030 compared to the current level. Since the municipalities have to implement this step, a guideline for municipalities on the climate-friendly design of parking fees is to be drawn up as part of this measure. The municipalities should then adapt their parking fee structures in accordance with the guidelines. • Objective: In order to reduce the attractiveness of conventional vehicles, the aim is to make parking more expensive, preferably for conventional vehicles. • Type: informative policy measure
Ancillary measure 4: "Target group-oriented information campaign on electric mobility"
• What: A target group-oriented information campaign is to be developed and launched to help overcome the reluctance and skepticism towards electric mobility. The target groups should be private users as well as commercial and fleet operators. • Objective: Closing knowledge gaps, reducing risk perception, supporting the purchase decision • Type: informative policy measure

Source: own elaboration.

Table 4. Overview of contributing impact studies in the IPPA process.

ID & Study Objective * by Policy Measure	Method	Discipline
Core measure 1: "CO_2 emission performance standards of 60 g/km by 2030"		
1-1: Impact of CO_2 limit values on vehicle fleet composition [n.a.]	cost calculation	innovation economics
1-2: Macroeconomic impact of climate policy instruments (CO_2 price, ETS) within different scenarios [17]	simulation (General Equilibrium)	energy economics
1-3: Impact assessment of CO_2 emission standards vs. CO_2 price instrument comparison [n.a.]	decision theory	institutional economics
1-4: Analysis of raw material availability (rare earth) for electro mobility [18]	simulation (Bayesian Algorithm)	environmental science
Core measure 2: "CO_2 price component for fossil fuels"		
2-5: Impact of user cost increase for conventional vehicles of 2% p.a. on the vehicle market [n.a.]	total cost of ownership	innovation economics
2-6: Law making and monitoring options for CO_2 price implementation [19]	legal analysis	law
2-7: Impact monitoring for CO_2 prices meeting the CO_2-reduction pathway of 55% by 2030 [n.a.]	simulation (system optimization model)	energy economics
2-8: Impact of policy measures (e.g., CO_2 price) on mobility behavior and demand [20]	simulation (agent-based model)	behavioral economics
Ancillary measure 1: "Reform of the motor vehicle tax"		
3-9: Impact of vehicle CO_2 tax reform on total mobility costs and vehicle fleet distribution [n.a.]	end consumer cost calculation	innovation economics
Ancillary measure 2: "Technology development for intelligent charging points & tariff systems"		
4-10: Analysis of capacity allocation options for integrating electromobility into the electricity system [n.a.]	decision theory	institutional economics
4-11: Analysis of various management models for implementing fast charging electric vehicle infrastructure [n.a.]	impact assessment	institutional economics

Table 4. *Cont.*

ID & Study Objective * by Policy Measure	Method	Discipline
Ancillary measure 2: "Technology development for intelligent charging points & tariff systems"		
4-12: Analysis of legal framework and problems for charging infrastructure [19]	legal analysis	law
4-13: Effectiveness of the use of intelligent charging points and vehicle fleet impact [n.a.]	simulation (system optimization model)	energy economics
Ancillary measure 3: "Guideline on parking fees"		
5-14: Analysis of various options for public parking space regulation [n.a.]	impact assessment	institutional economics
5-15: Impact of parking fee increase on mobility behavior patterns [n.a.]	representative survey in two cities	environmental psychology
Ancillary measure 4: "Target group-oriented information campaign on electric mobility"		
6-16: Impact of information campaigns pro electro mobility on different target groups [21]	simulation (agent-based model)	behavioral economics
6-17: Impact of information campaigns pro electro mobility among commercial customers [n.a.]	interviews, survey (conjoint analysis)	environmental psychology
6-18: Design of information campaign pro electro mobility for private households [n.a.]	survey (conjoint analysis)	environmental psychology
6-19: Analysis of willingness to switch towards alternative drive cars [n.a.]	representative survey in two cities	environmental psychology

Explanation: * = indication of publication or non-publication as not available (n.a.) in square brackets. Summary results on non-published material is available from the authors by request. Source: own elaboration

The evaluation phase integrated and synthesized the single impact studies into a coherent evaluation matrix. The integration aimed to deliver key insights on progress towards the mobility transition (intended impacts) and key insights on the unintended side effects and negative consequences. The evaluation of impacts needs to rely on multidimensional evaluation criteria that cover, to a certain degree, the heterogeneity of social-technical systems of humankind. We relied on a set of qualitative and quantitative criteria proposed for the transformation of energy systems [22]. Against the background of this set of criteria, all disciplinary studies were treated equally, and the criteria were not weighted. The focus was on a mosaic-like merging of the qualitative and quantitative results into an overall picture with regard to the impacts of the policy package. The set distinguishes five principal categories that address several dimensions of socio-technical systems and are equipped with corresponding criteria towards urban transport systems. The impact categories and their specifications are depicted below, while key results of the evaluation phase are listed in Table 5.

- Technology development: This includes criteria such as innovative mobility services, alternative drives for MPT, alternative drives for public transport, and intelligent charging infrastructure.
- Sector integration and coupling: This comprises the criteria of development of intelligent charging infrastructures and coupling of renewable electricity generation with the energy demand in transport.
- Environmental impact: This includes traditional emissions (air, water, soil, noise) and greenhouse gases, as well as the need for critical resources.
- Social resonance: This covers issues such as empirically measured willingness-to-accept (technologies, policy measures) and empirically measured consumption and investment behavior (households, companies).
- Institutional factors: This includes legal barriers (contradictions, inefficiencies, etc.), political barriers (e.g., overlapping competencies, mismatches between vertical governance levels, lobbying, time delays, etc.), spatial barriers, and economic barriers.

Table 5. Evaluation categories and criteria specified with results from the impact studies.

Criteria	Variables
Category I: Technology development	
Innovative mobility services	• Carpooling systems as on-demand shuttle based on electric vehicles
Alternative drives for MPT	• Diffusion of electric vehicles in MPT (private and public) • Range development • Cost development
Alternative drives for public transport	• Diffusion of electric vehicles in public transport
Intelligent charging infrastructure	• Development and establishment of intelligent charging infrastructure to avoid system instability
Category II: Sector integration	
Intelligent charging infrastructure	• Avoidance of negative effects of the diffusion of electric vehicles on the electricity system through the development of charging possibilities that are beneficial to the system
Coupling of renewable electricity generation with the energy demand in transport	• Electrification of the transport sector only serves climate protection if the growing demand for electricity is met by the additional expansion of renewable energy supply. • Electricity can be stored in battery electric vehicles directly at the time of generation, provided they are connected to the grid. • Electricity can be used in electrolysis plants to produce hydrogen at the time of generation. This can be stored and used for refueling independent of the electricity generation. • Electrification thus serves the purpose of sector integration.
Category III: Environmental impact	
Classical emissions to air, water, soil	• Production: mining and use of rare earths and critical resources (lithium, cobalt, platinum) may be problematic • Use phase: avoidance of NOx, reduction of fine dust, avoidance of further air pollutants in direct operation. Shift to electricity generation (if non-renewable energies are used)
Greenhouse gases	• Greenhouse gas emissions during the production phase, e.g., mining • Use phase: avoidance of CO_2 emissions in direct operation, shift to electricity generation if non-renewable
Critical resources	• Mining and use of rare earths and critical resources (lithium, cobalt, platinum)

Table 5. *Cont.*

Criteria	Variables
Category IV: Social resonance	
Empirically measured willingness-to-accept	• Increase in the cost of private transport: intention to switch may be high, but there is a risk of social imbalance; alternatives (public transport and alternative drives) must be available and usable. • Lack of information: there is a lack of neutral information and education about the technical characteristics and possibilities of alternative drives, which is why there is a great deal of skepticism about the new technologies.
Empirically measured consumption and investment behavior	• Purchase decision: depends on the level of information, the level of investment, the running costs, the technical characteristics such as range
Category V: Institutional factors	
Legal barriers	• Status quo: not everyone can participate equally (e.g., tenants cannot install a charging infrastructure). • Lack of procurement guidelines: there are (still) no guidelines for public procurement to give preference to alternative drives.
Political barriers	• Windows of opportunity: current problem pressure via EU specifications, society's climate protection claims (Fridays for Future) • Lack of coordination: activities of the car industry, the energy sector, and the state to establish charging infrastructures should be coordinated and more goal oriented
Spatial barriers	• Contextual dependency: use of alternative drives, if necessary, depending on the type of space (urban/rural), different incentives and systems of measures may be required
Economic barriers	• Investment costs: vehicles with alternative drive systems are significantly more expensive than conventional vehicles, lack of procurement guidelines

Source: own elaboration.

Within the discourse phase, we discussed the results with various practice experts. Each policy package with its evaluated impact profiles was subjected to discussion and review by practice-oriented members of the "ENavi competence teams" and further practice actors. The competence teams were a structural element of ENavi and included individuals from administration, civil society, and the economic sector concerned with issues around electricity, heat, and/or mobility. More detailed information on the case study results can be found in [2,3,23].

3.2. The IPPA Approach in the Face of TA, SR, and RRI

In our view, IPPA is an integrated approach with ties to several high-ranking problem-oriented research concepts concerned with societal transformations, including TA, SR, and RRI. In the following, we present in detail the common cross-cutting axes and similarities and deduce further research needs in the three fields of TA, SR, and RRI in the light of the IPPA approach.

3.2.1. TA: Linking Technology Assessment and Regulatory Assessment

The TA approach centers around (existing or forthcoming) technologies, with analysis and evaluation of its short- and long-term consequences concerning impact categories, such as societal, economic, environmental, ethical, legal, etc. [24,25]. Reaching back to the 1960s, TA became popular as science-based policy advice, serving regulators to consider negative side effects of existing and/or emerging technologies within their regulatory framework setting [26,27]. While starting as expert TA, technology assessment opened up towards more inter- and transdisciplinary approaches from the 1990s. Facets of modern TA concepts address:

- Constructive TA, which applies consequence assessment results to the early design and construction phase of technologies [28];
- The participatory TA approach, which aims to include lay people and stakeholders for their expertise and to confer legitimacy [29,30];
- TA and RRI [31,32], which "adds explicit ethical reflection to TA and merges both into approaches to shaping technology and innovation" [33].

Thus, the TA approach shows several distinctive accentuations and specifications over time.

IPPA is close to TA in a fundamental way. It combines the field of TA with the field of regulatory assessment. The IPPA approach was used in the urban passenger transport case study to develop a consistent and complementary policy package to stimulate substitution of combustion engines with alternative drives (electric mobility). This policy package aimed to meet CO_2 reduction targets in Germany and to boost positive impact effects and weaken negative side effects. Table 1 depicts the policy package for increasing alternative drives via CO_2 emission performance standards and a CO_2 price component for fossil fuels. To that end, the IPPA approach takes policy measures (bundled as a package) as the starting point for its assessment. When designing policy packages, the dissemination phase of technologies is in focus, assuming that the policies lead to intended technology dissemination and/or behavioral change. As such, it is not only the single technology consideration (for instance, electric mobility) which marks the research object of the IPPA approach but also the stimulating technology implementation policies. Thus, both objects—technologies and policies—are likewise assessment objects of the IPPA approach. Considering both policies and technologies, the impact assessment is carried out as shown in the urban transport example (cf. Table 4).

In our view, linking TA and regulatory assessment as operationalized by IPPA reveals the following benefits: (a) it focuses on the interplay of technologies with corresponding policy options, considering both transformation potential and impact analysis, (b) it assesses technologies considered at implementation and dissemination level, (c) it reflects upon the real-world embedment of policies and technologies in complex socio-technical systems, and (d) it serves as evidence-based advice for ex-ante trial without costly error exercises in policy-making. As an analytical, ex-ante thought experiment, it is an early warning tool for decision-makers, with indications of unwanted and risky side effects. The crucial IPPA stages providing TA benefit are the Design and Analysis phases. From our point of view, TA-based research could benefit from the policy assessment perspective within IPPA by ex-ante analysis of policy implications on the possible diffusion of, e.g., energy technologies.

3.2.2. SR: Addressing Deliberation Processes and Sustainable Pathway Identification

Sustainability has become the keyword for future orientation towards safeguarding societies worldwide in harmony with one another and the biosphere [34]. It is first and foremost a social construct that seeks to improve the quality of life for the world's peoples [35]. Sustainable development was concisely defined within the Brundtland Report in 1987: "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]. The Sustainable Development Goals (SDGs) are a collection of 17 interlinked global goals set by the United Nations in 2015 to achieve a better and more sustainable future. A key issue of sustainability is to integrate the three dimensions of economic, environmental, and social (including sociopolitical) wellbeing targets. SR documents the status quo reached, extrapolates and forecasts future developments, develops coherent sustainability transformation pathways, provides problem-solving metrics, indicators, and tool assessments, addresses ethics, conflicting goals, and deliberation processes, and helps to develop branch and sector-oriented sustainability specifications [36–41].

Within our IPPA approach, we tackle several relevant issues of SR, namely the field of deliberation processes and sustainable pathway identification. The concept of policy packaging should not focus only on the expected direct impact of the suggested measures but has to foresee unexpected side effects and unintended interrelationships with other sustainability goals. Impact assessment from a wide variety of disciplines, therefore, provided a multidimensional assessment picture in the areas of economic, environmental, and social dimensions (cf. Table 3).

The policy packaging process is carried out in four steps, with a starting point of the determination of one or more objectives to be addressed by the policy package, followed in the second step by an inventory of measures, preliminary measures, and causal assumptions, assessing one or more core measures. In the third step, an evaluation of effectiveness and efficiency was conducted, closely linked to a deep analysis of unintended effects [41]. Based on this analysis of the intended and unintended effects of the core measure(s), the final step considers whether the acceptance, effectiveness, and/or efficiency of the primary measure(s) can be increased through additional ancillary measures.

The interlinkage between SR and IPPA manifests at the latest in the third step of evaluating effectiveness and efficiency, where the principle of no significant harm has to be adopted, considering all SDGs. Consequently, consideration of effectiveness and efficiency were part of the development of the policy package, which focused on technological solutions for emission-free driving, such as battery electric vehicles, in order to rate the resulting demand for critical resources like cobalt and lithium, including possible social consequences in the countries of origin. A rising demand for these resources from other industrialized as well as developing countries, all aiming at climate-neutral energy and transportation systems, led to the insight that the purely technological approach of the policy package would probably not sufficiently contribute to the SDGs. Against the background of the applied evaluation criteria for the transformation of the energy system, this led to different conclusions regarding the evaluation criteria. This issue, which has a direct impact on the environmental impact evaluation criterion, also has an indirect impact on technology development. Here, the lack of sustainability must lead to further research and development activities that specifically aim to eliminate the critical raw materials, which has already been initiated in the case of cobalt. This would have been an important aspect for the modification of the policy package in the case of full implementation of the IPPA approach.

With regard to the criterion of social resonance, the issue of critical raw materials also needs to be addressed, especially if, as in the case of cobalt, it also entails critical social situations such as child labor in the mining country. Public perceptions of such issues potentially lead to reduced acceptance and limited effectiveness of the policy package. However, since the automotive industry already adequately addresses the issue described above as part of its sustainability policy and reporting, the issue is addressed and highlighted as part of the information campaign, which is envisaged as part of the policy package and is, therefore, already implemented in the holistically conceived policy package approach.

To give another example, it was part of the evaluation process to assess the consequences of the core measure "introduction of a CO_2-component in taxation" from a social perspective in order to figure negative distribution effects. Increasing the price of individual traffic based on fossil fuels to push battery electric mobility into the market was the main purpose. This could lead to social disruption, if no ancillary measures addressed the higher purchase price of battery electric vehicles and the fact that there is as yet no used-car market. In our view, it is highly important for further research to reflect on policy implications against the background of SR and, especially, to examine to what extent the ex-ante analyzed impacts of policy packages are compatible with the SDGs.

3.2.3. RRI: Social Resonance Assessment and Stakeholder Evaluation

The approach of Responsible Research and Innovation (RRI) [42] deals with the question of responsible design and governance of research and innovation processes. The underlying idea is to steer the research and innovation process towards societally beneficial objectives. Science and research on RRI were initially focused on technologies and processes with great societal transformation potential [43] as well as considerable scientific and ethical uncertainties [44]. Examples include nanotechnology, synthetic biology, and human brain research [45,46]. One of the causes of this focus, and an important driver for the promotion of RRI by research (funding) policy, is the intention of policymakers at European Union-level, in particular, to avoid an extended and highly controversial debate on technology, as there has been (and continues to be, in attenuated form) around genetic engineering [47]. In the recent RRI literature, the focus on transformative technologies is supported by the argument that the degree of collective accountability with which a particular activity or practice is to be undertaken must be proportional to the potential impact that the activity or practice might have on the world [44]. Socio-technical transformations such as the energy transition also have high impact, at least at the national (or European) level at which they take place. For socio-technical transformation processes to succeed, innovations for implementation of the transformation, such as technologies, infrastructural changes, business models, or policy measures related to such innovations, need to also benefit society in other respects in order to be widely used or supported [48]. It would be a mistake to assume that innovations that, in line with RRI's philosophy, are geared towards a societally desired goal (in the case of the energy transition, essentially a clean, secure, and affordable energy supply) will naturally be welcomed by society. The degree of diffusion or acceptance of the innovations also depends on the particular impacts (social, ecological) of the innovations themselves and the processes by which they were developed. From this perspective, RRI approaches also appear to be suitable to inform or guide socio-technical transformation processes such as the energy transition [49].

It is in this regard that the IPPA approach can be described as overlapping with RRI approaches. The overlap is mainly in the dimension's 'anticipation' and 'inclusion', which leading scholars of RRI have identified, together with 'reflexivity' and 'responsiveness', as the four integrated process dimensions of RRI [50]. The component 'evaluation' of IPPA includes that the different policy measures (or innovations in terms of new technology, infrastructure, policy, regulation) which compose the policy packages, and their interactions, are subjected to an ex-ante impact analysis informed by the results of a preceding interdisciplinary analysis. This corresponds with RRI's dimension of 'anticipation', which is about early assessment of "social, ethical and political stakes associated with technoscientific advances" [50] (p.1570). In the urban passenger transport case study, researchers evaluated the policy packages in regard to unintended environmental impacts and socially undesirable effects. Examples of this evaluation are provided in the preceding section on sustainability research. It is here that we see the main overlap between IPPA, RRI, and SR.

In the urban passenger transport case study, the main results of the impact analysis were subjected in the next step to critical review and feedback from various perspectives by practice actors at a science-practice workshop. At the workshop, participants from trade unions, technology development companies, transport companies, renewable energy associations, car-sharing associations, environmental protection organizations, municipal administration, and others discussed key results of the policy package development with the research team. The participants included members of ENavi's "competence teams", who had contributed feedback and input in earlier workshops with regard to identifying the main thematic foci (which included defossilisation of transport) and designing the policy packages.

The main objective of the urban mobility science-practice workshop was to identify possible blind spots concerning trade-offs and other challenges of implementing the developed policy packages into practice. One of the main requests from the workshop participants was to deepen the impact analysis in regard to what constitutes a socially fair transformation of the transport system. This request was combined with the emphatically formulated message to combine transformation of urban mobility with a mobility promise for rural areas. This mobility promise was found to be highly important to avoid or mitigate concerns that the specific situation of rural areas might be ignored or neglected in transportation policy. The inclusion of practice actors in the urban mobility study corresponds with the dimension of 'inclusion' of RRI. This dimension is about taking in the societal aspects of innovation and including both scientific and societal actors in research and innovation, especially when dealing with grand societal challenges [50,51].

A distinctive feature of RRI, as understood in large parts of the literature [52], is that steering innovation processes according to societal values and needs is interpreted as a collective responsibility. In the view of René von Schomberg, who is considered the originator of the RRI concept, models of responsible governance should be devised which allocate roles of responsibility to all actors involved in the innovation process: "A multidisciplinary approach with the involvement of stakeholders and other interested parties should lead to an inclusive innovation process whereby technical innovators become responsive to societal needs and societal actors become co-responsible for the innovation process by a constructive input in terms of defining societal desirable products" [53] (p. 70). In this view, there is not only an obligation (for example, for technology developers or policymakers) to organize inclusive and participatory processes but also an obligation on the side of societal actors to engage in a collective debate that shapes the context for collective decision making [54]. Further research in the field of RRI could benefit from the conceptual ideas of the IPPA processes by making knowledge of the multidimensional impacts of the policy packages visible and feeding it into the discourse when informing or guiding socio-technical transformations.

4. Discussion and Conclusions

In this paper, we have outlined the Integrated Policy Package Assessment (IPPA) approach and explored corresponding cross-cutting axes and common features of IPPA at the intersection with TA, SR, and RRI. In our understanding, the IPPA approach provides an example for operationalizing research in the field of TA, SR, and RRI. Development and implementation of IPPA was carried out by means of a case study on urban passenger transport in the context of the Kopernikus-project ENavi. It is organized as a four-phase model covering the stages of Design, Analysis, Evaluation, and Discourse. In this section, we summarize the major achievements and reflect on the academic benefits of the IPPA. We demonstrate how to apply the IPPA approach to other case studies, highlight major challenges, and draw some conclusions regarding both its political value and further research.

First, the major achievements can be summarized as follows: In short, we see the major benefit of the IPPA approach as linking evidence-based impact assessment with transformation pathway mechanisms and corresponding policy packages, backed by stakeholder-based responsible innovation feedback loops. We will briefly explain these interlinkages with reference to the three problem-oriented research concepts of TA, SR, and RRI.

In the area of TA, a main feature of IPPA is to focus on both technology assessment and regulatory assessment. With policy packages as a facilitator for transformational change, it includes emerging technologies, for instance, alternative drives in the mobility sector. The anticipation of possible intended and non-intended effects of policy packages and a reflection on socio-technical future pathways is a key feature of the IPPA approach. In addition, IPPA extends the classical TA approach to the analysis of the possible diffusion effects of technology and social innovations and related policies.

In the area of SR, the IPPA approach specifies sustainable pathway identification and considers deliberation processes via stakeholder integration and evaluation. Using the mobility transition as a framework, and specifically urban passenger transport as a case study, our analysis is closely related to normatively oriented SR and is thereby deeply entangled in public policy discourses and processes of policy advice. Furthermore, the sustainable pathway identification and the corresponding policy packages were embedded in the field of energy and mobility scenario modelling and future forecasting.

Cross-cutting axes with RRI represent consideration of social resonance parameters and assessment and stakeholder evaluation. The involvement of practice experts in our research on policy package development corresponds with the concept of RRI, which advocates inclusion of both scientific and societal actors in research dealing with grand societal challenges (RRI dimension "inclusion"). While classic RRI work focuses on "science and emerging technologies", the IPPA approach extends the view to other types of innovation, such as interlinked social and technical innovations, and reflects on unintended, socially undesirable effects and possible interactions between policy measures (RRI dimension "proactive impact assessment"). The multidimensional evaluation criteria set covers the different impact dimensions from a socio-technical perspective and thus helps to identify positive and/or negative impacts and resulting trade-offs. There is a need for further research with a view to a systematic evaluation of the RRI concept based on further empirical data, e.g., collected by means of a questionnaire filled out by each discipline, as has been shown in a study for the case of sustainable agri-food in Sub-Saharan Africa [55].

Second, in our view, the application of IPPA is adequate to link interdisciplinary with transdisciplinary knowledge and to advise decision-makers ex-ante regarding the possible desired and undesired impacts of foreseen policy packages. The approach is well-suited for case studies on the energy transition. Ideally, the transformation paths and their underlying policy packages and variables, i.e., the policies and their concrete design, should be demarcated as precisely as possible. This enables scientists to align their disciplinary analyses of consequences as closely as possible to the research subject and is, at the same time, an important success factor for the subsequent merging of the qualitative and quantitative results. The more specifically the object of investigation and its variables, i.e., the precise design of the policies, are defined in advance, the less open the research process and the more difficult it is to integrate "soft" knowledge about the impacts of the measures. Overall, one has to find an appropriate balance between the greatest possible specification and simultaneous openness in the research process and the integration of new findings into the results. From that point of view, the procedure in the IPPA approach provides a valuable opportunity to integrate disciplinary knowledge and combine it with stakeholder feedback loops from the start.

Third, the process of implementing the IPPA approach is a major challenge. The conceptual framework of IPPA is an ideal-type approach which is difficult to fulfil in real-world research practice. Implementation challenges arise from the following issues: the aims of considering policy packages with manifold impacts in socio-technical systems, the use of many impact studies from different scientific disciplines, the difficult task of integrating the heterogeneous results of the interdisciplinary impact assessment, and harmonizing timelines and time periods between those responsible for the process across the four process stages.

Fourth, taking these achievements and challenges together leads to the following conclusions: Integrated science approaches are essential features and, in our view, more than ever relevant for meeting the current 'grand challenges'. Added value from integrated approaches includes the early consideration of real-world complexities, uncertainties, and ambiguities. In that sense, the IPPA approach makes a valuable contribution to an integration of the three concepts: It brings together the areas of consequence analysis of technologies and regulatory impact assessment in the field of TA, it centers on transformation pathway identification towards sustainability in the field of SR, and it tackles responsibility and trust with stakeholder dialogue in the field of RRI. However, integrated science approaches for policy advice seem to remain the road to follow. In order to make the diverse impacts of individual policy measures visible in advance of their implementation, we are convinced that an interdisciplinary approach to analyze socio-technical energy futures is essential. If the results of IPPA are fed into the political decision-making process, this has a high political value, since the results of the IPPA allow the early analysis of policies in interaction (policy package) and thus enable decision-makers to analyze and compare different options with regard to the technical, economic, social, legal, etc., consequences. Additionally, this ex-ante analysis of policies without immediately implementing them minimizes the risk of making decisions that are difficult or impossible to correct regarding technological lock-in effects. However, the political deliberation process itself is not part of the IPPA, whose primary aim is to provide decision-makers with the necessary knowledge about the consequences of policy options. Regardless of this, stakeholder dialogues to uncover conflicts of interest or values and to address them in a targeted manner (to mitigate them and create transparency) serve as a suitable complement in the light of the IPPA results. Even if this road is a difficult one, the added value of integrated approaches is in the early consideration of real-world complexities, uncertainties, and ambiguities. It will be worthwhile to spend future efforts on trying to achieve solid and feasible concepts and practices.

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