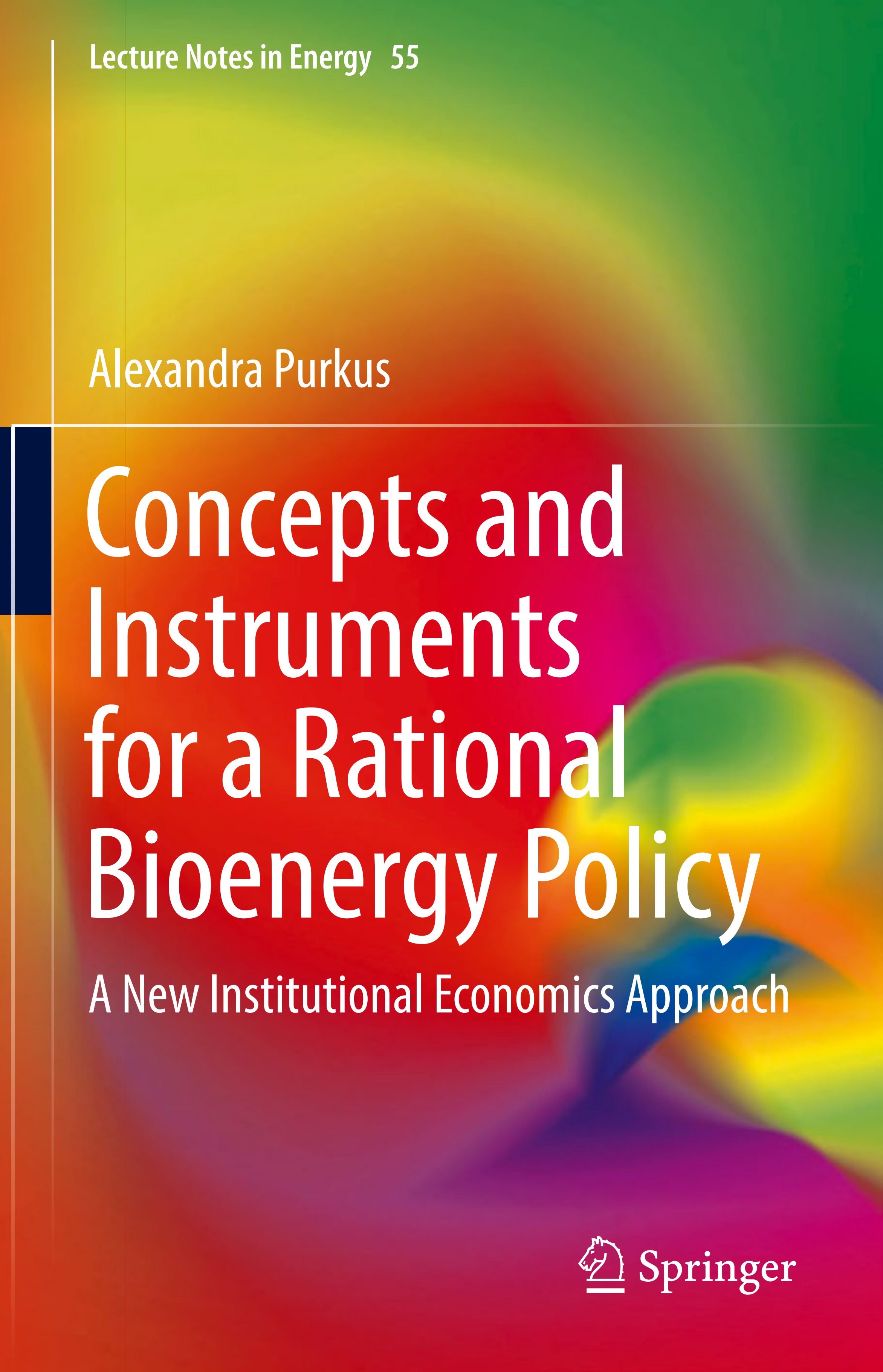

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Alexandra Purkus

Concepts and Instruments for a Rational Bioenergy Policy

A New Institutional Economics Approach

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Foreword

The use of renewable energies from biomass is connected with many hopes. In terms of climate policy, it promises a reduction of greenhouse gas (GHG) emissions in the context of satisfying a growing worldwide energy demand. At the same time, bioenergy provides urgently needed additional renewable energy sources, which are—in contrast to renewables from solar and wind—available on demand and can be used in a diverse manner: for electricity and heat production as well as for fuels. Additionally, it reduces the import dependency on scarce fossil fuels. Traditional agriculture and forestry expect a new surge in demand from bioenergy markets, and national economic policy sees export opportunities for biomass technologies as well as new sources of value creation for structurally weak areas. Against this background, it is no surprise that German and European policy heavily promoted the use of bioenergy in recent years.

However, bioenergy is widely criticised for threatening the food security of a growing global population due to the redirection of agricultural production factors towards the purpose of energy supply. Moreover, uncontrolled provision of bioenergy may result in global land-use changes, which may affect important ecological assets like biodiversity, hydrologic balance and soil integrity as well as socio-economic living conditions of people in the bioenergy regions. Even the supposed carbon neutrality of biomass use is undetermined if the change in land use for the cultivation of energy plants and their subsequent processing releases more CO_2 than the saving in energetic use compared to fossil fuels. In addition to ecological criticism, there is also economic critique concerning a policy that is too expensive for climate protection targets, as the cost for GHG reduction via bioenergy promotion may be unnecessarily high for society (compared to other means of GHG reductions). The reaction of German and European bioenergy policy to this criticism was a reduction of expansion goals and a modification of promotion instruments (e.g. sustainability requirements).

It is obvious that there are significant trade-offs between climate, energy and agricultural policy goals, and a reorientation of bioenergy policy on a scientific basis is urgently required. Between neoclassical concepts of a technology-neutral policy strictly focused on climate protection with the aim of least avoidance costs of GHG, which makes the specific promotion of bioenergy practically obsolete, and an unsteady “muddling through” approach of practical politics, a simultaneously scientifically substantiated and practice- and reality-oriented concept for a “rational bioenergy policy” is still missing.

With her dissertation, Alexandra Purkus aims to fill this research gap. She uses new institutional economic approaches, which are particularly suitable for this purpose. The overarching research goal of her PhD thesis is to bring together different strands of theory and literature to develop an analytical framework from which recommendations can be derived for a “rational bioenergy policy” that strives for efficiency and sustainability under various constraints (such as uncertainties, institutional path dependencies, transaction costs, etc.). In this way, policy recommendations are derived from an institutionally “enlightened” theory of economic policy, to identify solutions which deal with the constraints outlined above in a rational manner, and set dynamic incentives for efficiency and sustainability improvements over time. This is what is understood as “rational bioenergy policy” in the context of this work. Moreover, the issues are specified for the German bioenergy policy as a case study in the scope of the thesis.

On the one hand, the thesis covers a very relevant and current scientific issue, which is of high importance for German and European climate, environmental, energy, and agricultural policy. On the other hand, this methodological approach develops innovative theoretical perspectives of economic policy in a new policy field. They are scientifically very advanced compared to the present discussion and at the same time—especially because of the German case study—application relevant for practical bioenergy policy. This thesis is one of the few dissertations that clearly tries to cover a field of policy in its real complexity based on the example of bioenergy and under these aggravated institutional real-life conditions seeks to redefine the concept of a “rational economic policy” and to refine it for practical decisions in this policy field by using different new institutional economic theory approaches. Alexandra Purkus presents a very thorough, knowledgeable and strongly problem-oriented analysis, which is a great enrichment of the academic and policy-oriented debate, and will therefore reach a hopefully large readership.

Leipzig, Germany Erik Gawel
January 2016

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Contents

Abbreviations

a	Annum
AltholzV	Altholzverordnung (Waste Wood Ordinance)
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office of Economics and Export Control)
BBodSchG	Bundes-Bodenschutzgesetz (Federal Soil Protection Act)
BImSchG	Bundes-Immissionsschutzgesetz (Federal Immission Control Act)
Biokraft-NachV	Biokraftstoff-Nachhaltigkeitsverordnung (Biofuel Sustainability Ordinance)
BiomasseV	Biomasseverordnung (Biomass Ordinance)
BioSt-NachV	Biomassestrom-Nachhaltigkeitsverordnung (Biomass Electricity Sustainability Ordinance)
BMELV	Bundesministerium für Ernährung, Landwirtschaft und Verbraucher (Federal Ministry of Food and Agriculture and Consumer Protection); changed in December 2013 to BMEL—Bundesministerium für Ernährung und Landwirtschaft (Federal Ministry of Food and Agriculture)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety); changed in December 2013 to BMUB—Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
BMWi	Bundesministerium für Wirtschaft und Technologie (Federal Ministry of Economics and Technology); changed in December 2013 to BMWi—Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
BtL	Biomass to liquid

BWaldG	Bundeswaldgesetz (National Forest Act)
CAP	Common Agricultural Policy
CBA	Cost–benefit analysis
CHP	Combined heat and power
CO_2-eq.	Carbon dioxide equivalent
DüngG	Düngegesetz (Fertilisers Act)
DÜV	Düngeverordnung (Fertilisers Ordinance)
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
EEWärmeG	Erneuerbare-Energien-Wärmegesetz (Renewable Energy Heat Act)
EJ	Exajoule
el	Electric
EnergieStG	Energiesteuergesetz (Energy Tax Act)
EnEV	Energieeinsparverordnung (Energy Saving Ordinance)
EU	European Union
EU-ETS	European Emissions Trading System
FIP	Feed-in premium
FIT	Feed-in tariff
FQD	Fuel Quality Directive
GenTG	Gentechnikgesetz (Genetic Engineering Act)
GHG	Greenhouse Gas
GJ	Gigajoule
GWh	Gigawatt-hour
ha	Hectare
ILUC	Indirect land use change
KfW	Kreditanstalt für Wiederaufbau
KrWG	Kreislaufwirtschaftsgesetz (Closed Cycle Management Act)
ktoe	Kilotonne of oil equivalent
kWh	Kilowatt-hour
KWKG	Kraft-Wärme-Kopplungsgesetz (Combined Heat and Power Law)
LCA	Life cycle analysis
LUC	Land-use change
MAC	Marginal costs of abatement
MAP	Marktanreizprogramm (Market Incentive Programme)
MaPrV	Managementprämienverordnung (Management Premium Ordinance)
MB	Marginal benefits
MC	Marginal costs
MD	Marginal damage costs
Mio.	Million
MPS	Market premium scheme
MRS	Marginal rate of substitution
MRT	Marginal rate of product transformation
MRTS	Marginal rate of technical substitution

Mtoe	Megatonne of oil equivalent
MW	Megawatt
MWh	Megawatt-hour
N_2O	Nitrous oxide
NawaRo	Nachwachsende Rohstoffe (Renewable resources)
NIE	New institutional economics
NREAP	National Renewable Energy Action Plan
PFCs	Perfluorocarbons
PflSchG	Pflanzenschutzgesetz (Crop Protection Act)
PJ	Petajoule
PV	Photovoltaics
R&D	Research and development
RED	Renewable Energy Directive
REDD	Reducing Emissions from Deforestation and Forest Degradation
REH	Rational expectation hypothesis
RES	Renewable energy sources
SNG	Synthetic natural gas
SRC	Short rotation coppice
SRU	Sachverständigenrat für Umweltfragen (German Advisory Council on the Environment)
StromStG	Stromsteuergesetz (Electricity Tax Act)
t	Tonne
TCE	Transaction cost economics
TWh	Terawatt-hour
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
W	Watt
WBA	Wissenschaftlicher Beirat für Agrarpolitik (Scientific Advisory Board on Agricultural Policy)
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)
WHG	Wasserhaushaltsgesetz (Federal Water Act)
WTO	World Trade Organization

Chapter 1
Introduction

1.1 Opportunities and Challenges of Bioenergy Use

In the European Union as well as on a global level, biomass constitutes the most widely used renewable energy source (BMU 2013). Given its convertibility into solid, gaseous and liquid energy carriers, biomass can be used in the electricity, heating and transport sectors; moreover, bioenergy carriers are easily storable, allowing for a better alignment of energy supply with demand than is the case for intermittent renewables such as wind or photovoltaics, which are subject to natural fluctuations. As a result, the expansion of modern energetic biomass uses is considered an important component of transitioning to a low carbon energy system (COM 2005; BMU and BMELV 2009; Chum et al. 2011). Apart from reducing carbon emissions in the energy sector, bioenergy is expected to make contributions to the security of energy supply, while simultaneously offering opportunities for rural income generation and development (COM 2005; GBEP 2007). This combination of aims from environmental, energy, economic and agricultural policy arenas has made bioenergy attractive for political support—consequently, many governments have adopted ambitious expansion plans, among them the European Union, the United States, Brazil, and China (GBEP 2007; REN21 2014: 32ff.). For the EU, bioenergy plays an important part in realising renewable energy targets for 2020, as laid down in the Renewable Energy Directive (COM 2009). In order to achieve a 20 % share of renewable energy sources (RES) in community energy consumption and a 10 % share in transport, EU-27 member states expect energy production from biomass to more than double compared to 2005 levels, from 61 million tonnes of oil equivalent (Mtoe) in 2005 to 140 Mtoe in 2020 (cf. ECN 2011).

However, the rapid expansion of bioenergy use entails sustainability risks and increases competition between various alternative uses for land and biomass resources (Thrän et al. 2011a; Bringezu et al. 2008; WBGU 2008: 57ff.). Additional demand for biomass increases pressures on agricultural land use, thereby

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incentivising the conversion of natural land and increases in agricultural intensification (Berndes et al. 2010; Edwards et al. 2010). Apart from conflicts with conservation aims, emissions associated with land use change (LUC) can significantly deteriorate the greenhouse gas (GHG) balance of bioenergy (Fargione et al. 2008; Stehfest et al. 2010; Lange 2011; Sterner and Fritsche 2011). Moreover, displacing food and feedstock production with energy crop cultivation results in rising price levels for agricultural commodities, which may in turn negatively impact food security and cause indirect land use changes (ILUC) (FAO 2008; WBGU 2008; Searchinger 2009; Kampman et al. 2010; Nuffield Council on Bioethics 2011). Studies show that significant biomass potentials could be developed for energetic uses without increasing pressures on biodiversity, soils and water resources or negatively impacting global food security (Wiesenthal et al. 2006; WBGU 2008). However, for this to be the case, appropriate regulative measures and economic incentives need to be in place. Furthermore, it needs to be taken into account that not only various energetic uses increase the demand for agricultural biomass resources, wood and organic wastes and residues, but that interest in substituting fossil fuels for biomass is also growing in the material and chemical industry sectors (BMELV 2013; COM 2012a; OECD 2009). At the same time, bioenergy applications compete with other climate change mitigation options for public support, research funds and investment capital.

In a market framework, competition between various uses for scarce biomass and land resources would be coordinated by price signals. Neoclassical economic theory predicts that under conditions of perfect competition, markets will bring about an allocation that is efficient according to the criterion of Pareto optimality—in this case, all given resources are allocated in such a way that no one can be made better off by reallocations without making somebody else worse off (Mansfield 1994: 513f.; Fritsch 2011: 23ff.; see Sect. 2.1.1). The precondition for such a welfare-optimal allocation is that all relevant markets are in a state of general equilibrium (Mansfield 1994: 489ff.; Gawel 2009: 472ff.). However, in the case of bioenergy, allocation decisions are distorted by a number of market failures, leading to allocative outcomes which are no longer efficient and do not maximise welfare (see Sect. 2.2.3). In energy markets, technology decisions are distorted by GHG externalities associated with fossil fuel-based energy production, as well as other environmental externalities which arise, for example, in the course of uranium and coal mining or radioactive waste storage (cf. Krewitt and Schlomann 2006; Nitsch et al. 2004; Owen 2006; Breitschopf et al. 2011). These externalities interact with knowledge and learning spillovers, which are generated by investments in research, development and the diffusion of innovative technologies (Jaffe et al. 2005; Newell 2010; Arrow 2008; Lehmann 2013); these prevent market actors from capturing the full economic benefits of their investments. As a result, investments in innovative technologies which are associated with low levels of carbon emissions and other environmental externalities will be lower than socially optimal, increasing abatement costs from a dynamic perspective. Furthermore, a secure and reliable energy supply is associated with positive externalities, and energy producers may fail to undertake sufficient investments to prevent short- and long-term security of supply risks, for example by increasing the diversity of energy sources (Jansen and Bakker 2006: 40; Rader and Norgaard 1996: 40; Abbott 2001: 32; Langniß et al. 2007: 17). Lastly, energy sector investments have long lifetimes and require highly specialised investments in physical capital and skills and knowledge; this interacts with increasing returns and network externalities to create a technological path dependency (Arthur 1989, 1994). This path dependency is reinforced not only by market power on the side of incumbents, but also by institutional path dependencies, because existing institutions which shape energy markets and regulation have co-evolved historically alongside dominant technologies (Unruh 2000; Lehmann et al. 2012; Lehmann and Gawel 2013; Neuhoff 2005). In combination, this results in a "carbon lock-in" (Unruh 2000) into a fossil fuel-based energy system.

These market failures interact to distort competition between low carbon energy technologies, such as bioenergy pathways and other RES, and fossil fuel-based and nuclear incumbent technologies. However, they also distort competition between heterogeneous bioenergy pathways—particularly because GHG and other environmental externalities also cause market failures in the land use sector. The GHG emission reductions associated with bioenergy use depend not only on which energy carriers are substituted by bioenergy, but also on emissions caused by land use changes and during primary biomass production (WBGU 2008: 170ff.; Lemoine et al. 2010; Sterner and Fritsche 2011). In general, the use of residues and wastes, but also of wood, tends to perform better in terms of GHG mitigation than the use of agriculturally produced energy crops (WBGU 2008: 170ff.; Sterner and Fritsche 2011). However, using the latter can significantly expand the technical biomass potential available for energetic uses (cf. Chum et al. 2011: 17ff.; Thrän et al. 2010a). Simultaneously, energy crop-based pathways can show significant differences in GHG performance and other environmental impacts, depending on associated land use changes, crop choices, cultivation methods and specific spatial contexts (WBGU 2008: 57ff.; SRU 2007: 42ff.; Thrän et al. 2010b; Rossi 2012). Furthermore, the degree of knowledge and learning spillovers differs significantly between bioenergy technologies; options such as biogas and solid biofuel-based combined heat and power (CHP) production are comparatively mature (Thrän et al. 2011b: 42ff.; Gross 2004), while others, such as second generation biofuels, have high innovative potential (Eggert and Greaker 2013; Carriquiry et al. 2011; Sims et al. 2010). If left to markets, allocation decisions along bioenergy value chains would therefore be distorted in favour of options with low private costs and a high compatibility with the current, fossil fuel-dominated path in the energy system, while differences in greenhouse gas and other environmental externalities as well as positive externalities from investments in knowledge generation and learning were neglected.

According to neoclassical welfare economics, the existence of market failures in the energy and land use sectors provides a rationale for state interventions. These should restore the functionality of the price mechanism by internalising all relevant externalities and removing market power. Once the private costs and benefits of allocation decisions equalled the social costs and benefits and perfect competition was re-established, allocative efficiency would be restored—interventions such as these, which bring about a Pareto-optimal, welfare-maximal allocation, can be termed first-best interventions (Luckenbach 2000: 141). In practice, however, policy makers who intervene in bioenergy allocation decisions risk replacing market failures with government failures; these come about if interventions fail to correct market failures, or if they decrease efficiency even further compared to the market outcome (Fritsch 2011: 370). Government failures can result from a number of sources, such as: (i) conflicts between policy aims which seek to improve economic efficiency and distributive aims; (ii) information problems, for example, concerning the GHG balances and environmental impacts of bioenergy pathways; these are subject to significant uncertainties, particularly once indirect land use changes are taken into account (e.g. Reap et al. 2008; Cherubini and Strømman 2011; Edwards et al. 2010; DG Energy 2010; Adams et al. 2013); (iii) transaction costs of regulation, which may lie above the transaction costs of using even imperfect markets as coordination mechanisms; (iv) coordination problems between local, regional, national and transnational governance levels in governing bioenergy value chains which are increasingly transnational in character, as market actors make use of different countries' comparative cost advantages in biomass and bioenergy carrier production (Junginger et al. 2011; Lamers et al. 2011, 2012); and (v) conflicts between political and economic rationality.

Indeed, as interventions in energy markets with far-reaching consequences for biomass resource markets and land use markets, German and European bioenergy policies have attracted fierce criticism (see Sects. 3.1.4 and 4.4). Economists criticise that instead of relying on first-best measures for the correction of market failures, a number of technology-specific targets and deployment support instruments are employed (e.g. Frondel and Peters 2007; Frondel et al. 2010; Frondel and Schmidt 2006; Weimann 2008: 118f.; Sinn 2008: 161ff; Kopmann et al. 2009)—the latter are moreover fragmented across the electricity, heating and transport sectors, with little coordination between them (WBA 2007: 177ff.; SRU 2007: 88ff.; WBGU 2008: 325). The resulting policy mix reflects a range of efficiency-oriented and distributive policy aims with unclear prioritisation, so that in the end, bioenergy does not make cost-effective contributions to any of them (Isermeyer and Zimmer 2006; Henke and Klepper 2006). In particular, however, a failure to align allocation decisions with GHG mitigation as a priority aim is criticised (Henke and Klepper 2006; WBA 2007: 175ff.; Kopmann et al. 2009; Isermeyer and Zimmer 2006; SRU 2007: 80ff.; WBGU 2008: 274). Especially biofuels support policies are named as very expensive means of achieving GHG emission reductions (Frondel and Peters 2007; Henke et al. 2003; Henke and Klepper 2006; WBA 2007:177; Kopmann et al. 2009). Moreover, the sustainability of bioenergy policies is called into question—if introduced by several major economies, bioenergy support instruments increase pressures on land use globally, thereby exacerbating existing market and government failures in the land use sector (cf. WBA 2007: 180f.; WBGU 2008: 209; SRU 2007: 43ff.; Gallagher 2008: 29ff.; Miyake et al. 2012). Existing environmental framework conditions are found to be inadequate to safeguard against adverse environmental and socio-economic impacts of an additional, policy-driven biomass demand, both in non-EU biomass export countries (SRU 2007: 68ff.; Nuffield Council on Bioethics 2011: 90; Wunder et al. 2012) as well as within the EU (SRU 2007: 60ff.; Hirschfeld et al. 2008; Oppermann et al. 2012; Ammermann and Mengel 2011). At the same time, existing deployment support measures and instruments such as sustainability certification are found wanting when it comes to differentiating between bioenergy pathways according to environmental externalities and distributive impacts (WBA 2007: 181f.; SRU 2007: 60ff.; WBGU 2008: 318ff.; German and Schoneveld 2012; Schlamann et al. 2013).

1.2 Economic Advice for Bioenergy Policy: Between an "Ideal World" and "Muddling Through"?

Economic policy advice can make a valuable contribution towards assessing the manifold criticisms raised against existing bioenergy policies, and developing recommendations for a more rational policy design. Theory-based, economic contributions to the debate have been primarily based on neoclassical economics, with a focus on integrating bioenergy policy into a cost-effective GHG mitigation strategy: adopting GHG mitigation as the sole relevant aim with which bioenergy policy should be aligned allows for the identification of first-best interventions for the internalisation of GHG externalities. Once a GHG mitigation target has been set, the question becomes one of identifying an individual instrument which can implement this target effectively and cost-effectively; this approach follows the Tinbergen rule, which states that solving a certain number of targets requires at least an equal number of instruments (Tinbergen 1952; see Sect. 3.1). As a result, neoclassical economists recommend moving away from a sectorally fragmented policy mix which relies on technology-specific deployment support, and coordinate bioenergy allocation decisions through an extended emissions trading scheme instead (Frondel and Peters 2007; Klepper 2010; WBA 2007: 177f.; Kopmann et al. 2009). For optimising bioenergy's contribution to GHG mitigation targets, the instrument would need to span the electricity, heating, transport and, ideally, land use sectors, to account for GHG emissions associated with land use changes (Klepper 2010; Isermeyer and Zimmer 2006; Kopmann et al. 2009). Furthermore, to ensure an efficient allocation of abatement efforts and prevent leakage effects, the scheme would preferably need to be global in scope (Kopmann et al. 2009). With an extended emissions trading scheme, bioenergy pathways would only be adopted if they turned out to be competitive on the basis of GHG mitigation costs. Interdisciplinary policy recommendations, meanwhile, tend to be tempered by political feasibility considerations, but even here, the ideal of steering bioenergy allocation decisions through a cross-sectoral emissions trading system can be found as a long-term point of orientation, which is to guide the short-term alignment of sectoral policy instruments (cf. SRU 2007: 97f.; WBA 2007: 177ff.).

However, the applicability of these first-best recommendations rests on several highly idealised assumptions, which prove problematic when confronted with the multiple sources of market and government failures which are relevant in the bioenergy context (see Sect. 3.1.5):

1. The first-best approach to policy advice assumes that market failures can be considered individually when formulating policy recommendations, and that instruments can be optimised according to one policy aim. However, the theory of second-best emphasises the importance of interactions between multiple market failures (Lipsey and Lancaster 1956; Bennear and Stavins 2007; Lehmann 2012). If not all relevant market failures can be solved simultaneously by first-best solutions, the correction of one market failure in isolation may not necessarily increase economic welfare, because other, unresolved market failures may be exacerbated by the corrective intervention. A "second-best" intervention may consist of measures which address symptoms of interacting market failures, rather than first-best cures of their causes (Luckenbach 2000: 144). With a sector-spanning emissions trading system, for instance, abatement technology choices would remain distorted by knowledge and learning spillovers, so that efficiency can be improved by combining it with technology policy measures (Jaffe et al. 2005; Newell 2010; Bennear and Stavins 2007; Lehmann 2012).
2. First-best recommendations abstract from the transaction costs associated with the implementation, monitoring and enforcement of instruments, as well as with political decision making processes (Williamson 2005; Dixit 1996; Krutilla and Krause 2011). These would impose considerable limits on the feasibility and also the efficiency of a cross-sectoral, global emissions trading scheme (Lehmann and Gawel 2013).
3. Problems arising from uncertainty are considered only to a very limited degree, for example, in the choice between price and quantity instruments (Weitzman 1974), or target setting under uncertainty (Baumol and Oates 1971). However, the coordination of allocation decisions through an emissions trading scheme presumes an accurate accounting of GHG emissions (cf. Haberl et al. 2012), which is problematic given far-reaching uncertainties about GHG balances of bioenergy pathways.
4. By focussing on the efficiency rationale for state interventions in market processes, neoclassical theory neglects the relevance of distributive aims in political decision making. In the bioenergy context, distributive aims like rural value creation or employment generation in the RES industry play an important role; because they emerge from a democratic decision making process, they cannot justifiably be neglected (Sijm et al. 2014: 8).
5. Neoclassical recommendations view policy makers as disinterested welfare maximisers who design instruments with efficiency in mind; instead, policy making can be more accurately modelled as a negotiation and bargaining process, where self-interested policy makers attempt to maximise political support (Dixit 1996: 8ff.; Erlei et al. 1999: 323f.; Tullock 2008: 723). Political

rationality considerations can favour deviations from the Tinbergen rule; by attempting to address several efficiency-oriented and distributive aims with one instrument, the political feasibility of measures can be increased (cf. Gawel et al. 2014).

6. Neoclassical theory abstracts from the institutional context in which policy decisions and allocation decisions are taken. Institutions can be defined as "a rule or system of rules, a contract or a system of contracts (including enforcement mechanisms), which channel the behaviour of individuals" (Erlei et al. 1999: 23–25, own translation). Rules can be formal or informal in nature, and form an interacting, multi-layered system which has evolved over time (North 1990: 3; Williamson 2000; Richter and Furubotn 2003: 7). By constraining the interaction of boundedly rational individuals with imperfect information, institutions decrease the complexity of the decision making environment and economise on transaction costs (North 1990: 3). However, a given institutional framework may not be efficient and enact multiple distortions on allocation decisions—at the same time, institutional change is path dependent and mostly incremental in nature (North 1990: 92ff). By interacting with technological path dependencies, this can result in a lock-in into inefficient production and consumption structures, which cannot be overcome by an internalisation of externalities alone (Unruh 2000; Lehmann et al. 2012; Lehmann and Gawel 2013; Neuhoff 2005).
7. Lastly, even allocative outcomes which are efficient need not be sustainable, if normative requirements of inter- and intragenerational justice are applied (e.g. Daly 1992; Woodward and Bishop 1995; Padilla 2002; Krysiak 2009).

These considerations impose significant limits on the adequacy of neoclassical recommendations for bioenergy policy. By comparing existing market imperfections and policy interventions with solutions which would be ideal from a theoretical viewpoint, neoclassical policy advice risks following a "nirvana approach" (Demsetz 1969): practitioners of this approach "seek to discover discrepancies between the ideal and the real and if discrepancies are found, they deduce that the real is inefficient" (Demsetz 1969: 1). The actual feasibility of recommended measures, meanwhile, is neglected, considerably constricting the practical applicability of said advice.

As an alternative to the identification of optimal solutions based on theory, the term "muddling through" has been coined to describe a non-theory based decision and policy making strategy closer to the realities of the political process (Lindblom 1959, 1979). Here, policy choices are made on the basis of successive comparisons of alternatives which differ only incrementally, aided by experience about the differences in consequences that have been associated with incremental differences in policies in the past. Such an incremental approach allows not only for a simplification of the set of alternative policy options and consequences considered, but does not even require the definition of a clear hierarchy of policy aims—"agreement on policy thus becomes the only practicable test of the policy's correctness" (Lindblom 1959: 84).

However, a "muddling through" approach removes policies from a normative assessment. The German bioenergy policy mix, for instance, represents what has been chosen and agreed on by policy makers, and yet it has been widely criticised from an efficiency- and sustainability perspective—for evaluating these criticisms, a theoretical basis is necessary, to assess whether there may be feasible alternatives which perform better according to these criteria. Moreover, normative concepts like efficiency and sustainability are required to provide a counterweight to political rationality considerations. Public choice theory points out that it can by no means be assumed that incremental changes in policies will lead to improvements in their performance over time—instead, policy choices might reflect a redistribution of rents from less well organised groups in society to well organised interest groups (Olson 1965; Becker 1983; McCormick and Tollison 1981; Orchard and Stretton 1997: 412f.).

Furthermore, in the case of climate change policy, there is wide agreement between policy makers and scientists that a drastic reduction of GHG emissions is required in order to avoid global temperature increases with potentially catastrophic consequences (cf. IPCC 2013; UNFCCC 2014). Particularly industrialised countries which have a historical responsibility for high atmospheric carbon stocks face the challenge of undertaking a path transition away from the current technological and institutional carbon lock-in (Unruh 2000; Lehmann et al. 2012; Berkhout 2002). However, a wide range of actors and interest groups have invested specialised capital and skills into the existing "techno-institutional complex" (Unruh 2000: 818)—these would seek to influence incremental policy changes in their favour (Unruh 2002: 320f.; North 1990: 82; Kiwit and Voigt 1995; Leipold 1996: 107), thus reinforcing the lock-in.

Interactions between technological breakthroughs, social movements and exogenous focussing events (such as environmental catastrophes) can generate demand for more far-reaching policy changes, which propel innovative GHG mitigation technologies such as RES towards a market breakthrough (Unruh 2002). But, in designing these policies, there is limited experience on which an evaluation of incremental alternatives could build. European and member state-level targets for RES expansion and associated deployment support are fitting examples of this. Given the uncertainties surrounding such measures, the a priori identification of an optimal policy option which takes all relevant consequences into account is unrealistic—as the ongoing debate about how to address or even measure direct and indirect land use change effects as unintended consequences of bioenergy policies illustrates (Broch et al. 2013; Di Lucia et al. 2012; Gawel and Ludwig 2011; Van Stappen et al. 2011). On the other hand, ex post changes in bioenergy policy measures, which are implemented as part of a learning process, lead to an increase in policy uncertainty, which can compromise investors' willingness to respond to future climate policy initiatives.

Under such circumstances, a theory-based policy analysis which operates on assumptions closer to reality than those of a first-best neoclassical approach can make an important contribution towards more rational policy making. The focus here is not on the identification of optimal solutions, but on the systematic assessment of what policy alternatives may be better able to deal with relevant uncertainties and result in comparatively more efficient (and sustainable) outcomes than others (Demsetz 1969: 1; Dixit 1996: 8ff.; Williamson 2000). This approach has been successfully applied by new institutional economics (NIE), which can be described as the systematic, positive analysis of the effect that institutions have on human behaviour and social outcomes, as well as the normative analysis of their design (Erlei et al. 1999: 42; see Sect. 3.5).

While institutional change as a whole, which involves different nested layers of formal and informal institutions, is found to be incremental in nature (North 1990: 92ff.), individual institutions such as policy instruments can be amenable to more active design. For bioenergy policy, and climate change policy in general, NIE offers important theoretical insights regarding the design of such institutions, and their interactions with institutional layers which are more resilient to change. In placing economic policy recommendations for the bioenergy context on a more realistic footing, several NIE approaches seem particularly relevant—these are transaction cost and contract economics which compare the performance of governance structures between market and hierarchies in reducing uncertainties and economising on transaction costs (e.g. Williamson 2005; Dixit 1996; Krutilla and Krause 2011; see Sect. 3.5.2); the principal-agent approach which allows for an analysis of the implications of asymmetric knowledge between regulators and regulated market actors (Arrow 1984; Noth 1994; Haberer 1996; see Sect. 3.5.3); the theory of institutional change which examines the role of path dependencies and strategies for overcoming techno-institutional lock-in situations (North 1990, 1995; Brousseau et al. 2011; see Sect. 3.5.4); and the public choice approach which focuses on the role of interests in policy making (McCormick and Tollison 1981; Olson 1965; Mueller 1989; Orchard and Stretton 1997; see Sect. 3.5.5).

Besides NIE approaches, there are a number of other theories which examine the implications of realistic assumptions for policy making, making important contributions to economic policy advice that lie between the "muddling through" of day-to-day politics and the "ideal world" recommendations of neoclassical economics. For bioenergy policy, the following approaches have been identified as particularly relevant: the theory of second-best, which as mentioned above allows for a structured analysis of interactions between market failures (Lipsey and Lancaster 1956; Bennear and Stavins 2007; Lehmann 2012; see Sect. 3.2); information economics (e.g. Hayek 1945; O'Driscoll and Rizzo 1996; Young 2001; see Sect. 3.3) and the theory of economic order (Hayek 1945; Eucken 1952/1990; Wegner 1996; see Sect. 3.4), which both offer insights into political decision making and policy design under different forms of uncertainty; and ecological economics, with relevant findings regarding sustainability constraints and the handling of associated knowledge problems in policy making (Costanza et al. 1991; Costanza and Cornwell 1992; Funtowicz and Ravetz 1991; see Sect. 3.6).

These approaches have been fruitfully applied to a number of fields, including economic policy, organisation economics, and problems of environmental policy making. For climate and renewable energy policy issues, second-best theory and NIE have made significant contributions to the evaluation of policy mixes (for overviews see Lehmann and Gawel 2013; Sijm et al. 2014; Lehmann 2013) and instrument design (Menanteau et al. 2003; Finon and Perez 2007). In the bioenergy context, however, insights from relevant theories have been applied only to very specific questions so far, such as the role of information asymmetries in sustainability certification (Schubert and Blasch 2010), or the use of a post-normal science approach for dealing with sustainability-related uncertainties in bioenergy policy making (Upham et al. 2011). What is still missing is a systematic evaluation of where problems of bioenergy allocation and policy making show relevant deviations from neoclassical assumptions, and an assessment of how insights from theories that go beyond these assumptions can be combined to form a framework from which coherent economic recommendations for bioenergy policy can be derived. This book aims to address this gap.

1.3 Research Objectives

This study pursues two primary objectives. The first is to gain additional economic insights into the governance of complex environmental policy problems characterised by high uncertainty, multiple interacting market failures, institutional path dependencies and conflicting policy aims. The second objective is to use these insights to develop economic recommendations for the case of German bioenergy policy, which are closer to political realities than those based on the neoclassical construction of the problem, wherein the focus is on a single policy aim which strives for the correction of a single market failure, which can be addressed by a single first-best instrument in a way that allocative efficiency is restored (see Sects. 1.1 and 1.2). Drawing on NIE, second-best theory and the other approaches specified above, it is of interest whether neoclassical economists' rejection of technology- and sector-specific bioenergy deployment support instruments can be confirmed, or whether conclusions indicate a justification for their inclusion in a policy mix. In that case, the question would be how the existing policy mix could be improved on in terms of efficiency and sustainability.

In answering these research questions, three broad strands of relevant literature can be defined, which themselves draw on various theories. However, each of these strands shows limits when applied to the problems of bioenergy allocation, making it necessary to apply a synergetic approach.

First, there is the policy mix literature which focuses on the implications of multiple interacting market failures and multiple, potentially conflicting policy aims (Sect. 3.2). Besides insights from second-best theory, this strand of literature frequently incorporates NIE tenets such as the relevance of transaction costs, the embeddedness of policy instruments in a wider institutional framework and the existence of institutional path dependencies (Bennear and Stavins 2007; Goulder and Parry 2008; Ring and Schröter-Schlaack 2011; Lehmann 2012). For bioenergy policy, policy mix literature focussing on the interaction between climate and renewable energy policy instruments is particularly relevant. In contrast to neoclassical theory-based recommendations, it is shown that a coordinated policy mix consisting of an internalisation instrument, R&D subsidies and deployment support can improve efficiency compared to an individual instrument (see Lehmann and Gawel 2013; Sijm et al. 2014; Lehmann 2010, 2013 for comprehensive reviews). However, existing studies focus primarily on interactions between the EU-ETS or emissions taxes and a national-level feed-in tariff or another RES support instrument in the electricity sector (ibid.). In the case of bioenergy, the relevant policy mix needs to encompass the dimension of land use governance, as well as interactions between policy mixes in different energy sectors; moreover, given the transregional character of value chains, interactions between different governance levels need to be taken into account. Furthermore, there are various relevant aims that make demands on bioenergy use, plus the normative criterion of sustainability. Focussing in detail on a subset of interactions would, by necessity, involve neglecting other interactions: instead, this book aims to provide a structured account of relevant instruments, market failures and policy aims and their complex interactions. To be able to do this, a qualitative rather than a quantitative approach is chosen.

The second strand of relevant literature is made up of studies focussing on environmental policy making under uncertainty. This encompasses environmental economics contributions of instrument choice under uncertainty based on findings by Weitzman (1974) (see Sect. 3.1.2), NIE-based contributions focussing on asymmetric information problems (Sect. 3.5.3) or institutional learning and adaptation processes (Sect. 3.5.4), applications of information economics insights on decision making under various types of uncertainty to environmental problems (Sect. 3.3), and ecological economics approaches focussing on handling sustainability constraints under uncertainty (Sect. 3.6). For the application to bioenergy policy, limits arise from the diverse character of contributions, which use different sets of assumptions and frequently focus on very specific policy or decision making problems. Here, this book's contribution is to examine and synergise insights for the formulation of a bioenergy concept which takes the role of uncertainty in different stages of the policy making process into account, from decision making to institutional design and implementation.

Thirdly, transaction-cost economics-based literature on respective advantages of hierarchical governance structures and governance structures close to markets proves relevant (Sect. 3.5.2). Originally applied in an organisation economics context (Williamson 1975, 1985), findings have since been transferred to problems of policy making (Dixit 1996; Krutilla and Krause 2011; McCann 2013). Moreover, the topic has also been the focus of works on economic policy based on the theory of economic order (Eucken 1952/1990; Hayek 1967/2003; Wegner 1996; see Sect. 3.4). While the latter emphasise the advantages of decentralised allocation decision making, transaction cost economics findings imply that under some conditions, hierarchical governance structures can perform better than market-based ones; this has also been found for the problem of instrument choice in renewable energy policy, for example, when comparing quota schemes close to markets with more hierarchical feed-in tariffs (Finon and Perez 2007; Menanteau et al. 2003).

Differentiating between various climate change mitigation options or renewable energy technologies is difficult enough for policy makers, but the heterogeneity of bioenergy pathways adds a degree of complexity. In the electricity sector, for example, it is not only a matter of differentiating between say, bioelectricity, wind power, photovoltaics and so on, but differences in GHG balances and other environmental and socio-economic impacts raise the question of how to differentiate within the bioelectricity technology group. The same is true for different biomass-based pathways in the transport and heating sectors. This study adds to the literature on the governance of technology choices between market-based and hierarchical approaches by analysing the question of technology differentiation within a heterogeneous technology group.

The overall approach of this study, therefore, is to bring together different strands of theory and literature to develop an analytical framework from which realistic, yet theory-based recommendations for bioenergy policy can be derived. The central question is what characterises a “rational”, economic theory-based bioenergy policy, which acknowledges efficiency and sustainability as normative guidelines, while navigating a path between various interacting market failures and potential government failures. In this context, it is the task of economic policy advisors to offer recommendations which are closer to reality than a first-best nirvana approach, but avoid the arbitrariness of a “muddling-through” approach.

Meanwhile, given the scope of the topic and the regulative problems involved, the aim of this book is not to provide detailed recommendations for each aspect of bioenergy policy. Instead, guidelines for a rational bioenergy concept will be developed, which can then be applied to different contexts. However, even on a conceptual level, the institutional environment that bioenergy policy making is embedded in is an important factor that needs to be taken into account when formulating recommendations. Here, for reasons outlined below, German bioenergy policy has been chosen as a case study. Also, the focus is on national-level policy making and design, although interactions with other governance levels are taken into account. This focus has been selected because currently, major incentives for bioenergy use originate from national level policy decisions and instruments. Additionally, to explore its applicability to more detailed instrument recommendations, the analytical framework developed in this study is applied to the specific question of how bioelectricity support schemes should be further developed under the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG).

1.4 Relevance of the German Case Study

The German case study is highly relevant for a number of reasons. Germany was among the early movers in supporting the expansion of biofuels and bioelectricity pathways on a significant scale (cf. Beurskens and Hekkenberg 2011; Thornley and Cooper 2008; Londo and Deurwaarder 2007). Biomass use in heating applications is an established practice in a large number of countries, but the simultaneous expansion of biomass use in all three energy sectors (see Sects. 4.1.3 and 4.1.4) is particularly interesting from an allocative point of view because it amplifies competition for biomass resources and increases coordination requirements between sectoral policy measures. Given that a number of EU and non-EU countries plan to expand their bioenergy use in several sectors (GBEP 2007; Beurskens and Hekkenberg 2011), important lessons can be learned from the German case.

Moreover, the comparability of Germany's bioenergy policy mix to other EU member states is high—all of them apply a policy mix of EU-ETS and national instruments for renewable energy support, which are mostly designed in a technology- and sector-specific manner (Winkel et al. 2011; RES LEGAL 2015). Some elements of national renewable energy policy design, such as minimum sustainability standards for biofuels and bioliquids, or RES targets in the transport sector, are harmonised by EU regulations (see Sect. 4.1.2). Moreover, member states share the Common Agricultural Policy (CAP), and national environmental framework regulations have to be aligned with EU requirements. The transferability of general findings from the German case study is therefore likely to be high, although more specific recommendations, for example, concerning instrument choice and design, would have to be adjusted to national contexts.

Finally, German bioenergy policy is an interesting case study because over the last decade, clear changes can be observed in its strategic orientation. In the mid-2000s, political commitment was expressed for an expansion of bioenergy use and renewable resource cultivation (Federal Government of Germany 2005: 42f.; BMELV 2007). The use of energy crops for electricity production was specifically incentivised through a renewable resource bonus introduced in the EEG 2004 (cf. Witt et al. 2012: 100; Delzeit et al. 2012), while tax incentives for biofuels and later the biofuel quota supported the expansion of energy crop-based first generation biofuels (FNR 2012; Naumann et al. 2014: 31ff.). In 2009/2010, policy makers continued to emphasise support for an expansion of bioenergy use in all three energy sectors, but further energy crop potentials were increasingly regarded as limited, placing the focus for further expansion on wastes and residues and technical efficiency increases (BMU and BMELV 2009: 8; Federal Government of Germany 2010: 94ff.; BMWi and BMU 2010: 10). In 2014, bioelectricity policy in particular has been revised with a strong emphasis now being placed on cost-effectiveness aspects, shifting away from energy crops as well as from remaining high-cost waste and residues as potential energy sources (Federal Government of Germany 2013: 39; BMWi 2014: 11f.). In the transport sector, the shift towards a GHG-based biofuel quota, which entered into force in 2015, likewise places greater emphasis on waste and residues-based concepts (Naumann et al. 2014: 3f.). The turn away from energy crop-based bioenergy concepts is also mirrored on the EU policy level, where deliberation on direct and indirect land use change impacts (COM 2010, 2012b) has resulted in the recent introduction of a cap on food-based biofuels in EU-level biofuel policy targets (European Parliament 2015). Meanwhile, shifts in strategic orientation have been accompanied by changes in instrument design which have at times been abrupt, leading to no small degree of policy uncertainty on the part of investors. For countries which have yet to implement comprehensive bioenergy strategies or still wider bioeconomy strategies, an analysis of these developments in the light of theoretical insights on policy adjustments can yield useful insights.

1.5 Structure and Contents

This book is divided into six chapters, Chap. 1 being the introduction. Chapter 2 conducts an economic analysis of the allocative challenges associated with bioenergy use. More specifically, it examines what problems arise when allocation decisions are coordinated by market forces alone (Sect. 2.2), and what challenges apply to regulative interventions in the market mechanism (Sect. 2.3). As such, the analysis provides the basis for subsequent chapters which examine responses to these challenges. As central normative criteria for evaluating the allocative outcome of market processes or government interventions, the requirements of efficiency and sustainability are discussed (Sect. 2.1). It is shown that when allocative problems such as the steering of biomass flows and technology choices, the setting of incentives for dynamic efficiency and innovation, and the steering of location choices and sourcing decisions are solved by the market mechanism alone, the outcome will not be efficient (Sect. 2.2). Several market failures are identified which distort allocation decisions (Sect. 2.2.3), namely environmental externalities, security of supply externalities, knowledge and learning externalities, the occurrence of market power in the energy sector, and dynamic market failures that inhibit market adjustment processes. Moreover, interactions between market actors are subject to information problems and transaction costs. Meanwhile, the analysis points out that even if the market outcome was efficient, it need not be sustainable. Policy interventions, on the other hand, are also unlikely to bring about an outcome which meets efficiency and sustainability criteria, because of the relevance of conflicting aims (Sect. 2.3.1), information problems and transaction costs (Sect. 2.3.2), the multi-level governance nature of the regulative problem (Sect. 2.3.3), and conflicts between political and economic rationality considerations (Sect. 2.3.4). Indeed, German and European bioenergy policy making shows clear empirical evidence for the relevance of these sources of government failure (Sect. 2.4). For assessing policy interventions in allocation decisions, requirements for a rational bioenergy policy are defined, which take the constraints imposed by imperfect information and political feasibility into account (Sect. 2.1.3). However, the analysis demonstrates that the multiplicity of relevant, interacting market failures and sources of potential government failures makes compliance not only with sustainability and efficiency criteria, but also with rational bioenergy policy requirements a challenging task.

Chapter 3 develops the analytical framework which is used in Chap. 5 to derive recommendations for German bioenergy policy. First, neoclassical theory implications for bioenergy policy, as well as their limits, are discussed (Sect. 3.1). To move towards more realistic theory-based policy recommendations, the analysis draws on the theory of second-best (Sect. 3.2), information economics (Sect. 3.3), the theory of economic order (Sect. 3.4), and new institutional economics (Sect. 3.5), and gives an outlook on ecological economics implications (Sect. 3.6). For each of these theories, relevant findings are discussed and applied to bioenergy policy, leading to the derivation of theoretical guidelines for bioenergy policy design (Sect. 3.7.7). It is demonstrated that when developing a comprehensive framework for bioenergy policy analysis, no individual theory addresses all relevant aspects, and that a combination of theoretical approaches is necessary to generate recommendations which adequately reflect the complexity of the policy problem. However, among the theories considered, new institutional economics approaches are found to be particularly fruitful for the generation of valuable insights for bioenergy policy recommendations. Here, the matrix of institutions which jointly influence allocation decisions by bioenergy actors is at the centre of the policy analysis. Among new institutional economics approaches, transaction cost economics (Sect. 3.5.2), the principal-agent approach (Sect. 3.5.3) and the theory of institutional change (Sect. 3.5.4) provide valuable insights for generating policy design recommendations in the presence of uncertainty and transaction costs in the various stages of decision making and policy implementation. Furthermore, the theory of institutional change and the public choice approach (Sect. 3.5.5) help explain the persistence of inefficiencies, and highlight the importance of political constraints when assessing the feasibility of policy recommendations. Because of the central insights that an institutional perspective offers for the analysis of bioenergy policy, new institutional economics is chosen as the overall framework into which insights from other theories are integrated.

Chapter 4 moves on to the German case study. While the analyses undertaken in Chaps. 2 and 3 are not specific to Germany, but generate general theoretical insights that apply to bioenergy allocation and policy making, the development of concrete recommendations requires that the institutional context be taken into account. Chapter 4 therefore provides an overview of relevant political framework conditions for German bioenergy policy. As a focus, European and national policy levels are chosen, because it is here that major incentives for bioenergy use originate (Sects. 4.1 and 4.2). It is shown that bioenergy policy affects a wide range of policy aims from diverse policy areas, and that the political prioritisation of aims has changed over time (Sect. 4.1.1). Also, the strategic long-term focus of bioenergy policy is the subject of ongoing discussions (Sect. 4.1.3). Meanwhile, alongside diverse policy aims, there is also a complex mix of policy instruments that influence bioenergy allocation decisions (Sect. 4.2). Instruments identified as the most relevant for bioenergy allocation include command-and-control instruments and market-based incentive instruments, which can be further divided into indirect instruments which increase the costs of fossil fuel substitutes and direct instruments which set positive incentives for bioenergy use. Direct, sectoral instruments such as the EEG in the electricity sector (Sect. 4.2.3), the Renewable Energy Heat Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG) and the Market Incentive Programme in the heating sector (Sect. 4.2.4), and the biofuels quota in the transport sector (Sect. 4.2.5) are found to be the most relevant policy drivers for bioenergy expansion in Germany. Besides setting incentives for bioenergy use in the utilisation sphere, they also—to varying degrees—influence the choice of conversion technologies and feedstocks.

Following the overview of political framework conditions and the identification of primary drivers, Chap. 4 assesses the German bioenergy policy mix in relation to the market and government failures discussed in Chap. 2 (Sect. 4.3) and reviews major strands of critique in the public debate (Sect. 4.4); in particular, these refer to the lack of cost-effectiveness in realising contributions to GHG mitigation and the limited effectiveness of sustainability safeguards. The chapter concludes with a review of comprehensive recommendations for reforming the German bioenergy policy mix, which have been proposed by interdisciplinary expert panels (Sect. 4.5), to allow for a comparison to the NIE-based policy advice developed in this book.

Chapter 5 addresses the research objective of developing concrete recommendations for bioenergy policy, applying the theory-based analytical framework developed in Chap. 3 to the German case study. The focus is on recommendations for a rational bioenergy policy concept, which encompasses the definition of a system of consistent policy aims, the choice of allocative principles for bioenergy governance, and the identification of suitable instrument types to implement aims (Sect. 5.1). As such, conceptual recommendations do not intend to solve every detailed question of policy formulation, but act as a reference system for individual policy decisions. Moreover, to demonstrate the applicability of the study's analytical framework to more specific questions of instrument choice and design, recommendations for the bioelectricity sector are developed in greater detail (Sect. 5.4). For each element of the bioenergy concept, neoclassical solutions are outlined, to act as a baseline against which NIE-based findings can be compared; then, there is a discussion of which theoretical insights from Chap. 3 are particularly relevant for analysing the system of policy aims, the choice of allocative principle, and instrument choice and design (Sects. 5.2–5.4). These insights are used to evaluate current German bioenergy policy, and derive recommendations for the three elements of a bioenergy concept.

Given the conflicting nature of policy aims, the establishment of a complete and coherent system of policy aims is found to be of particular importance, although public choice theory highlights the difficulties of such an endeavour (Sect. 5.2). Also, requirements concerning the operationalisation of aims are discussed. The choice of allocative principle determines what allocation mechanism is used primarily to implement aims—basic allocative principles are the use of governance structures comparatively close to markets, which leave technology choices to market actors, and the use of governance structures with a more hierarchical steering of allocation decisions (Sect. 5.3). Different allocative principles are found to be recommendable for governing different transactions in bioenergy value chains, depending on their specific characteristics. In contrast to neoclassical recommendations, a theoretical case is established for a bioenergy mix combining governance structures close to markets with more hierarchical interventions. Also, the work examines what types of interventions are most promising when it comes to addressing interactions between interventions which increase bioenergy demand, unresolved market failures and conflicting policy aims. Based on the analysis of what allocative principles are recommendable for different allocative challenges, perspectives for the further development of the German policy mix are discussed (Sect. 5.3.3).

For a more detailed analysis of instrument choice and design, a further focus is necessary; direct bioenergy support in the electricity sector is chosen as an example, because here, a major reform process is currently underway (Sect. 5.4). For addressing the allocative challenges of bioelectricity use, three elements of instrument choice and design are identified as particularly important: (1) the choice between price, quantity and hybrid instruments; (2) the design of a mechanism for technology differentiation; and (3) the design of an adjustment mechanism, which is strongly interwoven with the two previous questions of instrument choice and technology differentiation. For these three elements, theoretical insights are discussed and applied to an evaluation of the current feed-in tariff/feed-in premium scheme as well as relevant instrumental alternatives. Based on a comparative institutional analysis, recommendations are derived.

Chapter 6 concludes with a summary of major findings (Sect. 6.1), discusses the transferability of the study's analytical framework to other policy contexts (Sect. 6.2), and provides an outlook (Sect. 6.3).

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